Republic of Iraq

Ministry of Higher Education

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University of Babylon

OPTIMUM OPERATION OF THE FIRST PART OF THE MAIN OUTFALL DRAIN

A thesis
Submitted to the Civil Engineering Department of the College of Engineering, University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of Science in Water Resources Engineering

By

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(February 2008)

بسم الله الرحمن الرحيم

وَهُوَ ٱلَّذِي أَنزَلَ مِنَ ٱلسَّمَاءِ مَاءً فَأَخْرَجْنَا بِهِۦ نَبَاتَ كُلِّ شَيْءٍ
فَأَخْرَجْنَا مِنْهُ خَضِرًا نُّخْرِجُ مِنْهُ حَبًّا مُّتَرَاكِبًا وَمِنَ ٱلنَّخْلِ مِن
طَلْعِهَا قِنْوَانٌ دَانِيَةٌ وَجَنَّٰتٍ مِّنْ أَعْنَابٍ وَٱلزَّيْتُونَ وَٱلرُّمَّانَ
مُشْتَبِهًا وَغَيْرَ مُتَشَٰبِهٍ ٱنظُرُوٓاْ إِلَىٰ ثَمَرِهِۦٓ إِذَآ أَثْمَرَ وَيَنْعِهِۦٓ إِنَّ فِي
ذَٰلِكُمْ لَآيَٰتٍ لِّقَوْمٍ يُؤْمِنُونَ

صدق الله العظيم

سورة الأنعام

﴿الآية ٩٩﴾

To my family, relatives and friends,

especially for My husband

and My son

Hussain

We certify that we have read this thesis entitled **"The optimum operation of the first part of the Main Outfall Drain"**, and examined the student **Thura Razzaq Ajam,** in its contents and what is connected with it, and that in our opinion it meets the standards of a thesis for the **Degree of Master of Science in Water Resources Engineering.**

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Table (A2-1): Areas of agricultural projects of the first part of MOD. [After: BAD, (2006)]

Project name		Total agricultural area (donum)	Agricultural area of summer season (donum)	Agricultural area of winter season (donum)
1	Al-Saqlawiya	132700	28370	51895
2	Al-Ishaqi	90000	26200	64000
3	Sabaa-Al Bor	180700	38460	56970
4	Abughraib	164500	44750	80200
5	Al-Radhwaniya1	60000	11100	23200
6	Al-Radhwaniya2	89700	25050	42625
7	Al-Yusufiya	250000	83400	95555
8	Hor Rajab	120000	35148	45401
9	Al-Latifiya	179000	45100	90400
10	North Mussaiyab	165000	41793	70485
11	Jbala	143000	59470	40100
12	Kusaiba	180000	46900	60360
13	South Mussaiyab	160000	54229	72078
14	Al-Shuhaimiya	198000	70300	90600

CERTIFICATION

We certify that this thesis entitled **"The optimum operation of the first part of the Main Outfall Drain"**, was prepared by **Thura Razzaq Ajam**, under our supervision at the Civil Engineering Department, University of Babylon, in partial fulfillment of the requirements for the **Degree of Master of Science in Water Resources Engineering.**

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التشغيل الأمثل للجزء الأول من المصب العام

ثرى رزاق عجام

بكالوريوس هندسة مدنية \ ٢٠٠٠

المستخلص

إن الحالة التطبيقية لهذا البحث هي الجزء الأول من المصب العام ، (كم صفر-كم ١٥٥)، ومحطات الرصد الخمس القائمة تقسم الحالة التطبيقية إلى أربعة أجزاء رئيسة. إن الحالة التطبيقية تخدم (١٤) مشروعا زراعيا، ومواقع مصبات مبازل المشاريع المخدومة مع محطات الرصد القائمة تقسم الحالة التطبيقية إلى (١٤) جزءا ثانويا.

استخدمت طريقة Muskingum لاستتباع الجريان في الحالة التطبيقية، من جزء ثانوي إلى الذي يليه، وجرى تحديد قيم العناصر (Δt), (K), (x) بطريقة التجربة والخطأ. وقد تم إعداد برنامج أمثلية لتقويم حالة الجريان والعائد الزراعي بالاعتماد على مؤشرات تقويم بوحدات نقدية افتراضية، (MU).

بالإضافة إلى سيناريو (الكثافة الزراعية القائمة) في المشاريع الزراعية المخدومة، تم تقويم أربعة سيناريوات أخرى افتراضية تضمنت كثافات زراعية (٥٠٪), (١٠٠٪), (١٢٥٪), (١٦٠٪).

استنادا إلى النتائج المشتركة لبرنامجي استتباع الجريان والامثلية فقد تم التوصل إلى الاستنتاجات التالية:

١- قيم (Δt) لل (١٤) جزء ثانوي التي تشكل الحالة التطبيقية هي 8, 4, 1, 2, 4, 3 ,2, 10, 1, 2, 3, 6, 4, 9 ساعات، على التوالي.

٢- قيم (K) المقابلة كانت ($\Delta t \times 2 = K$).

3- قيم (x) للأجزاء الثانوية المذكورة انفا كانت 0.15، 0.40، 0.20، 0.15، 0.40، 0.30 ، 0.15، 0.15، 0.15، 0.15، 0.10، 0.10، 0.10، 0.10، على التوالي.

4- باعتبار الكثافة الزراعية (100٪) كأساس للمقارنة ، فان (الكثافة الزراعية القائمة) أعطى أفضل نتيجة بقيمة دالة الهدف الكلية التي بلغت (MU 2.899.953).

5- باعتبار ان حدي الكثافة الزراعية (50٪) و (160 ٪) ، فان اختبار مجاميع افتراضية مختلفة من الكثافات الزراعية لكل من المشاريع المخدومة بالحالة التطبيقية بين بان اعتماد الكثافات الزراعية 160٪ ، 160٪ ، 160٪ ، 150٪ ، 125٪ ، 125٪ ، 100٪ ، 125٪ ، 120٪ ، 120٪ ، 150٪ ، 140٪ ، 120٪ ، 120٪ ، للمشاريع المخدومة، على التوالي ، سيجعل الحالة اقرب إلى المثلى إذ جاءت قيمة دالة الهدف الكلية (MU 4.666.751).

6- لم تظهر أي دلالة على إن التصميم الحالي للحالة التطبيقية مبالغ فيه أو انه اقل من المناسب.

ABSTRACT

The case study for this research is the first part of the Main Outfall Drain, Km. (0) to Km. (155). The case study is divided into (4) main reaches by the five existing observations stations. It serves (14) agricultural projects. The locations of the outfalls of the drains of the served projects, together with the observation stations, divide the reach into (14) subreach.

The Muskingum method is used to route the flow in the reach, from one subreach to the next. The values of the routing parameters (Δt), (K), and (x) have been determined by a trial-and-error approach.

An optimization model is established to evaluate the combination of the flow state in the case study and the return from the cropped area, based on some proposed evaluation parameters expressed in monetary units (MU).

Beside the actually-cropped area in each of the fourteen agricultural projects served by the case study, four proposed agricultural densities (AD) have been evaluated, namely (50%), (100%), (125%), and (160%); a total of five tested operation scenarios.

Based on combination of the results of the routing and optimization models, the following conclusions have been arrived at:

1- Values of (Δt) for the (14) subreaches forming the case study are 8, 4, 1, 2, 4, 3, 2, 10, 1, 2, 3, 6, 4, and 9 hours, respectively.
2- The respective values of (K) are ($K=2\ \Delta t$).
3- The values of (x) for the aforementioned subreaches are 0.15, 0.40, 0.20, 0.15, 0.40, 0.30, 0.15, 0.15, 0.15, 0.15, 0.10, 0.10, 0.10, and 0.10, respectively.

4- Considering (AD=100%) as the base for comparison, the (AD=actual) came the best , yielding a total objective function, (TF) of (2,899,953 MU).
5- On considering (50% ≤ AD ≤ 160%), the test of a variety of combinations of proposed agricultural densities for the involved (14) agricultural projects revealed that a strategy of (AD%) of 160, 160, 160, 150, 125, 125, 100, 125, 120, 120, 150, 140, 120, and 120, respectively, gives a better nearly-optimum (TF) of (4,666,751 MU).
6- The present design of the case study is neither over-design nor under-design.

CHPTER ONE
INTRODUCTION

1-1 : Importance of drainage

Iraq has large fertile area and relatively ample fresh water. This enabled it to establish and develop extensive irrigation projects.

Because the district of the middle and south of Iraq, especially the area between Euphrates and Tigris rivers ,has a mild slope and its soil is sedimentary, beside using savage flooding as the common irrigation method, a significant portion of irrigation water have accumulate in the agricultural area.

Before the establishment of the State Organization of Soil and Land Reclamation (in 1957), the irrigation projects were designed and built not accompanied with drainage projects. However, the few drainage projects executed at those days have been designed such that drainage water is drained to a close river or depression. The latter have created marshes and small lakes in different regions of the middle and south of Iraq. The successive accumulation of such water created very high water table in the vicinity of a lot of agricultural lands so that drainage became a most necessity.

Drainage of districts needs a major intake to collect and dispose the drained water. This is the main idea behind the design and execution of the Main Outfall Drain in Iraq. The Main Outfall Drain has been achieved by great efforts as well as a lot of money. Due to its importance in the agriculture allover the country, the operation of this project in an optimum way or nearly an optimum way is something necessary for the people.

1-2 : Objective of the research

The main objective of the research is to arrive at the optimum operation of the first part of the Main Outfall Drain for selected practical agricultural and hydrological scenarios.

1-3 : Methodology of the research

The research adopts the following methodology:

1- Daily recorded discharge data are needed in this research but they are not available. Consequently, the available monthly data shall be processed to yield the respective daily records.

2- On reviewing the routing procedures in use, the one most suitable for the case study shall be applied. The selected routing procedure shall be so-formulated that it fits the chosen case study, namely, the first part of the Main Outfall Drain.

3- The formulated mathematical model, after calibration and verification, shall be used to predict the respective outflow hydrographs for some selected agricultural scenarios.

4- An optimization model shall be established and run to arrive at the most practically-feasible agricultural plans for the agricultural projects served by the first part of the Main Outfall Drain such that the drain will operate in an optimal fashion.

CHAPTER TWO

REVIEW OF LITERATURE

Chapter two involves three subjects, namely, the hydrologic and hydraulic flood routing in open channels, then the optimization of the operation of channels. The review of literature shall concentrate on these three main subjects.

Among the so many researches available in this respect, only some representative examples are reviewed.

2-1 : Flood routing

Flood routing, as defined by **Fread, (1981)** and **Linsley et al., (1982)**, is a mathematical method for predicting the changing magnitude and celerity of a flood wave as it propagates down rivers or through reservoirs. Numerous flood routing techniques, such as the Muskingum flood routing methods, have been developed and successfully applied to wide range of rivers and reservoirs. Flood routing procedures may be classified as either hydrologic routing or hydraulic routing. Moreover, flood routing methods are categorized into two broad, but somewhat related applications, namely, reservoir routing and open channel routing [**Lawler, (1964)**]. These methods are frequently used to estimate inflow or outflow and peak flow rates in reservoirs, river reaches, farm ponds, tanks, swamps, and lakes.

Several factors should be considered when evaluating the most appropriate routing method. The factors that should be considered in the selection process include backwater effects, floodplains, channel slope, hydrograph characteristics, flow network, and subcritical and supercritical flow [**USACE, (1994)**].The selection of a routing model is also influenced by other factors such as the type and availability of data, the available computational facilities, the extent of flood wave information desired, and the familiarity of the user with a given model.

Flood routing is important in the design of flood protection measures in order to estimate how the proposed measures will affect the behavior of flood waves in rivers so that adequate protection and economic solutions can be found [**Wilson, (1990)**]. In practical application, two steps are involved in the prediction and assessment of flood level inundation. A flood routing model is used to estimate the outflow hydrograph by routing a flood event from an upstream flow gauging station to a downstream location. Then the flood hydrograph is input to a hydraulic model in order to estimate the flood levels at the downstream site [**Blackburn and Hicks, (2001)**].

2-2 : Hydrologic flood routing

A major problem in hydrologic engineering is flood routing. Hydrological methods are still widely used for this purpose, especially where data concerning the geometry of the channel are not available, but the volumes entering and leaving the section are known. This method is based on the continuity equation and relationship between storage volume and inflow and outflow in the river section.

Windsor, (1973) used recursive linear programming procedure for operation of a flood control system employing the Muskingum method for hydrologic routing for reservoirs computations.

Singh and Quiroga, (1986) developed a mathematical model for earthern dam breach erosion. Two aspects are emphasized, namely, the evaluation of the dam breach and the subsequent flood and sediment routing. They used the Muskingum method to simulate flow exchange between channel and flood plain and to route the resulting breach hydrograph .A sediment routing to simulate deposing in flood plains and deposition and scouring in the channel was based on the Muskingum method too.

Labadie, (1988) used the Muskingum method as a flood routing model in order to calculate the routing coefficients of the channel reaches in the Han River

Basin, Korea. He selected the values of **(**x**)** for the main channel reaches equal to **(**0.2**)** and the parameters of (K) were determined based on the data.

Karim, (1998) studied the flood routing in the Tigris River between Mosul and Baiji. The study involves a comparison between hydrologic and hydraulic flood routing methods. He found that the hydraulic flood routing method gives the most accurate results.

Marechal and Holman, (2003) made comparison of hydrologic simulation using regionalized and catchments –calibrated parameter sets for three catchments located in East Anglia, eastern England .The coefficient of correlation results of the three catchments (0.700, 0.560, 0.480) compare well with another study in one of the catchments using another hydrologic model specifically calibrated and are within the range of the results from other simulation studies in ungauged catchments in England, Australia, Canada, and Norway.

Risley et al., (2004) made flood routing simulations for the three landslides-induced overtopping floods over a 530-Km reach of the Bartag and Panj rivers below Usoi Dam, Tojikistan. A one dimensional flow model using a Rieman numerical solution technique was selected for analysis.

Gombo et al., (2004) applied a number of flood routing models (linear regression model, Muskingum linear routing model, and Muskingum–Cunge model) for Kherlen River Basin, Mongolia. The Muskingum model provided the best simulation results, while the error of Muskingum-Cunge model was too high (30-40%) which is unacceptable, and linear regression model gave different values for (K).

Smithers and Tewolde, (2005) applied the Muskingum-Cunge method for flood routing in three sub-catchments in the Thukela catchment in Kwazulu-Natal, South Africa with river lengths of (4, 21, and 54 Km).The Muskingum (K) and (x) parameters were estimated for each reach on the basis of empirically (MC-E) and on the basis of assumed (selected) channel cross-section (MC-X).They found that the estimated values of the flow variables in the (MC-E) and (MC-X) methods resulted in computed hydrographs with acceptable error .

ASCE, (2006) used the Broyden Fletcher Goldfarb Shanno, (BFGS), technique. The technique found the best parameter values of (K) and (x) compared to previous results in terms of the sum of the square deviation between the observed and routed outflows, using the smallest number of computational iterations. A sensitivity analysis showed that the initial values of certain parameters were critical when finding the optimal solution. Although this gradient-based technique makes use of initial value assumptions and involves complicated calculus, different initial values reach the same optimal or near-optimal solution within less time.

Shrestha and Nastmann, (2006) made comparison between four different modeling approaches for water level simulation, using the same flood event data from the years 1988, 1990, 1993, and 1994 for a reach of about (100 km) from the Rivers Rhine and Neckar in Germany. The models include hydrodynamic numerical, (HN), model, a Muskingum Cunge, (MC), model, and two data driven models: artificial neural network, (ANN), and adaptive network based fuzzy inference system, (ANFIS) .The results showed that the (MC), (ANN), and (ANFIS) models performed better compared to the (HN) model.

Wesley et al., (2006) developed a coupled hydrologic –hydraulic model by integrating two decades of modeling achievement with new algorithms specially designed for this case, employing updated modeling techniques and utilizing improved spatial and temporal data. Furthermore, this model was used to analyze storage scenarios necessary to mitigate 1997-type floods and probable maximum flood in the Red River of the north borders North Dakota and Minnesota and flows north towards lake Winnipeg in Manitoba, Canada.

2-3 : Hydraulic flood routing

Hydraulic methods of routing involve the numerical solution of either the convective diffusion equations or the one-dimensional Saint-Venant equations of gradually varied unsteady flow in open channels [**France, (1985)**].

Cunge and Woolhiser, (1975) used the movable gates to make control upstream and downstream an open channel. They established an efficient mathematical model to simulate the flow under the gate (submerged or free).

Haktanir and Acanal, (1997) developed a computer program to perform calculations of the six-stage flood routing model. The model is applied sequentially to Yedgoze, Catalan, and Seyhan Dams, all on Seyhan River in Turkey.

Al-Msaudi, (2001) applied the Saint-Venant equations to make hydraulic control on Shatt Al-Hilla upstream Hilla City by using a cross-regulator with (6) gates downstream the reach .

Radwan and Sadek, (2002) used hydraulic structures to regulate the river Dender in Belgium during dry summer periods to protect several areas from flooding .

Othman, (2006) made hydraulic control on Shatt Al-Hilla within Hilla City from (km 32.000) to (km 51.500) by changing some hydraulic parameters (the flow depth, side slope, bed width, and Manning's (n) for the reach).

2-4 : Optimum operation of channels

Optimum operation of a channel (whether a supply one or a drain) implies minimizing the operation cost (or time) for the normal state of flow and the two conflicting states, namely, flood and draught .Current water logging and salinity problems and rising water tables are the result of persistent seepage from unlined canals in the extensive distribution system and irrigation surpluses from fields .The optimum operation of drainage has become essential because the productivity of irrigated lands is declining.

Ali, (1978) presented the analysis of a complex water resources system for multiple use of water. The system includes six reservoirs and two major streams located on the Teedule River in the United Kingdom. The problem was to minimize objective function which depended on release of water and storage states.

Sadiq, (1985) optimized the operation of the Diyala River system, using monthly inflow for twenty years. The results have been used to define a useful set of release rules in an actual operation of the river .

Mays and Olcay, (1989) used nonlinear programming model with flood routing simulation model for the real-time optimal flood operation of a river-reservoir system .Application of the model is illustrated through a case study of Lake Travis on the lower Colorado River in Texas .

Saleh (1989) applied dynamic programming to develop optimal monthly release policies for the Euphrates River system in Iraq. He showed that a quantity of water should be diverted from upstream Ramadi Barrage to Habbaniya Lake in order to control flood downstream the barrage and refresh Habbaniya Lake by almost continuous mixing.

Al-Delewy, (1995) developed and tested a mathematical model for the operation of a complex water resources system, taking the Diyala River system as a case study.

Muslim, (1997) developed a computer program to improve the water quality of the Third River northern section by EC and (SAR) values within the allowable limits for irrigation. This has been suggested to be done by the construction of desalination plants on the drains along the river operating with minimum cost to achieve the desired pollutants limits.

Mishra et al., (2005) used the integrated optimization model to the Right Bank Main Canal system of India. Simulation were performed for autumn irrigation periods of three different years(1995-1997). Three simulation scenarios are considered to reduce the gap between irrigation water supply and crop water demand.

The hydraulic routing generally describes the flood wave profile adequately when compared to hydrologic techniques, but practical application of hydraulic routing is restricted because of their high demand on computing technology as well as on quantity and quality of input data .Even when simplifying assumptions and approximations are introduced, the hydraulic techniques are complex and often difficult to implement [**Linsley et al., (1982)**].

Studies have shown that the simulated outflow hydrograph from the hydrologic routing always have peak discharge higher than those of the hydraulic routing method. However, in practical application, the hydrologic routing methods are relatively simple to implement and reasonably accurate [**Chow et al., (1988)**].

CHAPTER THREE

THE MATHEMATICAL MODEL

3-1: Waves in natural channels

Simple mathematical treatment of flood waves is necessarily limited to uniform channels with fairly regular cross section. However, the hydrologist must deal with non uniform channels of complex section with non uniform slope and varying roughness.

Most flood waves are generated by non uniform lateral inflow along the channels of the stream system. Thus, natural flood waves are considerably more complex than the simplified cases[**Linsley et al., (1982)**].

3-2 : Channel routing

Channel routing is the term applied to methods of accounting for the effects of channel storage on the runoff hydrograph.

For a given upstream hydrograph and channel system, a number of routing methods are available to route the hydrograph through the stream reach. The methods to be introduced here are examples of the simplified routing methods that often referred to as hydrologic routing methods. More complex methods referred to as hydraulic routing methods are available.

3-3 : The Muskingum flood routing method

Among the many models used for flood routing in rivers ,the Muskingum model has been one of the most frequently used tools because of its simplicity [**Tung, (1985)**]. The Muskingum method of flood routing has been extensively applied in river engineering practices since its introduction in the 1930s; it is so called because it was first developed by the USCE in connection with flood control schemes in the Muskingum River Basin, Ohaio [**Henderson, (1966)**].

For the purpose of developing an equation for routing through either stream channels or reservoirs, the continuity of mass can be expressed as :

$$\mathbf{I - O = \frac{\Delta S}{\Delta t}} \qquad (3\text{-}1)$$

where:

$\mathbf{I} =$ inflow, (L^3/T);

$\mathbf{O} =$ outflow, (L^3/T);

$\mathbf{\Delta S = S_{i+1} - S_i} =$ storage between two consecutive routing times, (L^3);

$\mathbf{\Delta t = t_{i+1} - t_i} =$ time between two consecutive routing time steps, (T).

The continuity equation can be expressed in terms of the inflow (upstream) and outflow (downstream) at times ($\mathbf{t_{i+1}}$) and ($\mathbf{t_i}$) . Expressing Eq. (3-1) in terms of the average inflow and average outflow at time ($\mathbf{t_{i+1}}$) and ($\mathbf{t_i}$) gives:

$$\mathbf{\frac{1}{2}\left(I_i + I_{i+1}\right) - \frac{1}{2}\left(O_i + O_{i+1}\right) = \frac{S_{i+1} - S_i}{\Delta t}} \qquad (3\text{-}2)$$

where: (i) and (i+1) denote two consecutive times.

For steady uniform channel flow, the inflow, outflow, and storage are functions of the depth of flow, (**D**). Assuming that the stage-discharge relationship (i.e., the rating curve) is a straight line on log-log paper, the discharges ($\mathbf{I}$) and ($\mathbf{O}$) can be represented by [**Richard, (2005)**]:

$$\mathbf{I = aD_I^{\,d}} \quad \text{or :} \quad \mathbf{D_I = \left(\frac{I}{a}\right)^{\frac{1}{d}}} \qquad (3\text{-}3a)$$

and

$$\mathbf{O = aD_O^{\,d}} \quad \text{or :} \quad \mathbf{D_O = \left(\frac{O}{a}\right)^{\frac{1}{d}}} \qquad (3\text{-}3b)$$

Equations (3-3) have the same coefficients (**a)** and **(d),** which implies that the properties of the stream reach are relatively constant. The storage characteristics at the upstream and downstream sections [(S_I) and (S_O), respectively] are also assumed constant with storage and depth and assumed to be related through a log-log relationship [**Richard, (2005)**] :

$$S_I = bD_I{}^m \tag{3-4a}$$

and

$$S_O = bD_O{}^m \tag{3-4b}$$

In the preceding equation, (**b**) and (**m**) are constants.

Solving Eq.(3-3) and substituting the solution into Eq.(3-4) yields:

$$S_I = KI^{\frac{m}{d}} \tag{3-5a}$$

and

$$S_O = KO^{\frac{m}{d}} \tag{3-5b}$$

where: K=[$\frac{b}{a^{\frac{m}{d}}}$] is denoted as the routing coefficient, having the dimension of time (T).

Assuming that the weighted-average storage S is a weighted function of the storage at the upstream and downstream cross-sections. With a weighting factor (**x**), (**S**) could be expressed as:

$$S = x\,S_I + (1-x)S_O \tag{3-6}$$

Substituting Eqs.(3-5) into Eq.(3-6) gives:

$$S = xKI^{\frac{m}{d}} + (1-x)KO^{\frac{m}{d}} \tag{3-7}$$

The Muskingum method assumes that $\frac{m}{d} = 1$.Thus, the storage function, Eq.(3-7), becomes:

$$S = K[xI + (1-x)O] \tag{3-8}$$

which is the basic equation in the Muskingum routing approach.

Substituting Eq.(3-8) into Eq.(3-2) and collecting and rearranging the terms, the result is usually set in the form, commonly denoted as the Muskingum routing equation, that is:

$$\mathbf{O_{i+1} = C_{\circ}I_{i+1} + C_1I_i + C_2O_i} \qquad (3\text{-}9)$$

where:

$$\mathbf{C_{\circ} = -\frac{Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t}} \qquad (3\text{-}10a)$$

$$\mathbf{C_1 = \frac{Kx + 0.5\Delta t}{K - Kx + 0.5\Delta t}} \qquad (3\text{-}10b)$$

$$\mathbf{C_2 = \frac{K - Kx - 0.5\Delta t}{K - Kx + 0.5\Delta t}} \qquad (3\text{-}10c)$$

Summing the three coefficients shows that:

$$\mathbf{C_{\circ}+C_1+C_2=1} \qquad (3\text{-}11)$$

where:

$\mathbf{C_{\circ}}$**,** $\mathbf{C_1}$**,** $\mathbf{C_2}$=Muskingum routing coefficients

The upstream hydrograph is routed through the reach using Eq. (3-9) provided that the initial estimate, ($\mathbf{O_i}$), must be specified. It is also necessary to specify the routing interval, $\Delta\mathbf{t}$.

While the Muskingum method has been widely used for decades, values of the coefficients (K) and (x) are not available from the analysis of measured hydrographs. A general rule of thumb is that (K) can be estimated by the travel time through the reach. The values of (x) can be used from (0) to (0.5). A value of (0.5) for (x) is usually considered to be the upper limit of rationality. This value suggests equal weighting of inflow and outflow. A value of (0) for (x) is the practical lower limit and suggests that the inflow has no effect, which would reflects reservoir-storage-type effects in which attenuation would be dominant. Some have reported values for (x) in the range from (0.4) to (0.5) for natural channel streams, while others suggest values from (0.1) to (0.3) for natural streams, with (x) equal to (0.2) commonly assumed [**Richard, (2005)**].

3-4 : The case study

3-4-1 : The Main Outfall Drain

The Main Outfall Drain, (MOD), is one of the biggest drainage projects in the world. Its benefits serve about (6 million donum)of agricultural lands and reduce the pollution due to salinity in Tigris and Euphrates rivers and lower the water table in middle and south of Iraq .

The Main Outfall Drain is a central drainage system collecting contaminated water from major drainage projects and conveys it to the sea. The length of MOD is (565 Km), beginning from west of Baghdad, (Km 00), to Shatt Al-Arab, (Km 565). The Main Outfall Drain is divided into three unequal parts. The northern part, beginning from west of Baghdad to the Dalmage lake; the middle part, beginning from Dalmage lake to the pumping station in Nasiriya City; and the southern part, beginning from the pumping station to Shatt Al-Arab. The MOD is over-crossed along its course by one railway bridge, 21 road bridge, and 33 foot bridge. Figure (3-1-a) is a general map showing the first part (northern part), second part (middle part), and third part (southern part) of MOD. Figure (3-1-b) shows the cross section of MOD. Table (3-1) shows the hydraulic design for the Main Outfall Drain.

3-4-2 : The application case

The first part of MOD, (northern part), from (Km 00) to (Km 155), has been taken as the case study for this research. Figure (3-1-c) is a location map showing the drains that end to the first part of the MOD. The first part of MOD is divided into four reaches, namely, (S_1-S_2), (S_2-S_3), (S_3-S_4), and (S_4-S_5). These reaches are denoted R1, R2, R3, and R4, respectively. Each reach is divided into subreaches according to the drains of that reach; the reach (R1) is divided into three subreaches, namely, SR1, SR2, and SR3. Reach (R2) is divided into three subreaches too, namely, SR4, SR5, and SR6. Reach (R3) is divided into four subreaches, namely, SR7, SR8, SR9, and SR10. Reach (R4) is divided into four subreaches too, which are SR11, SR12, SR13, SR14 and SR15. The first part of MOD serves fourteen agricultural projects and involves five gauging stations as shown in Figure (3-1-d) [**BWRD, (2006)**].

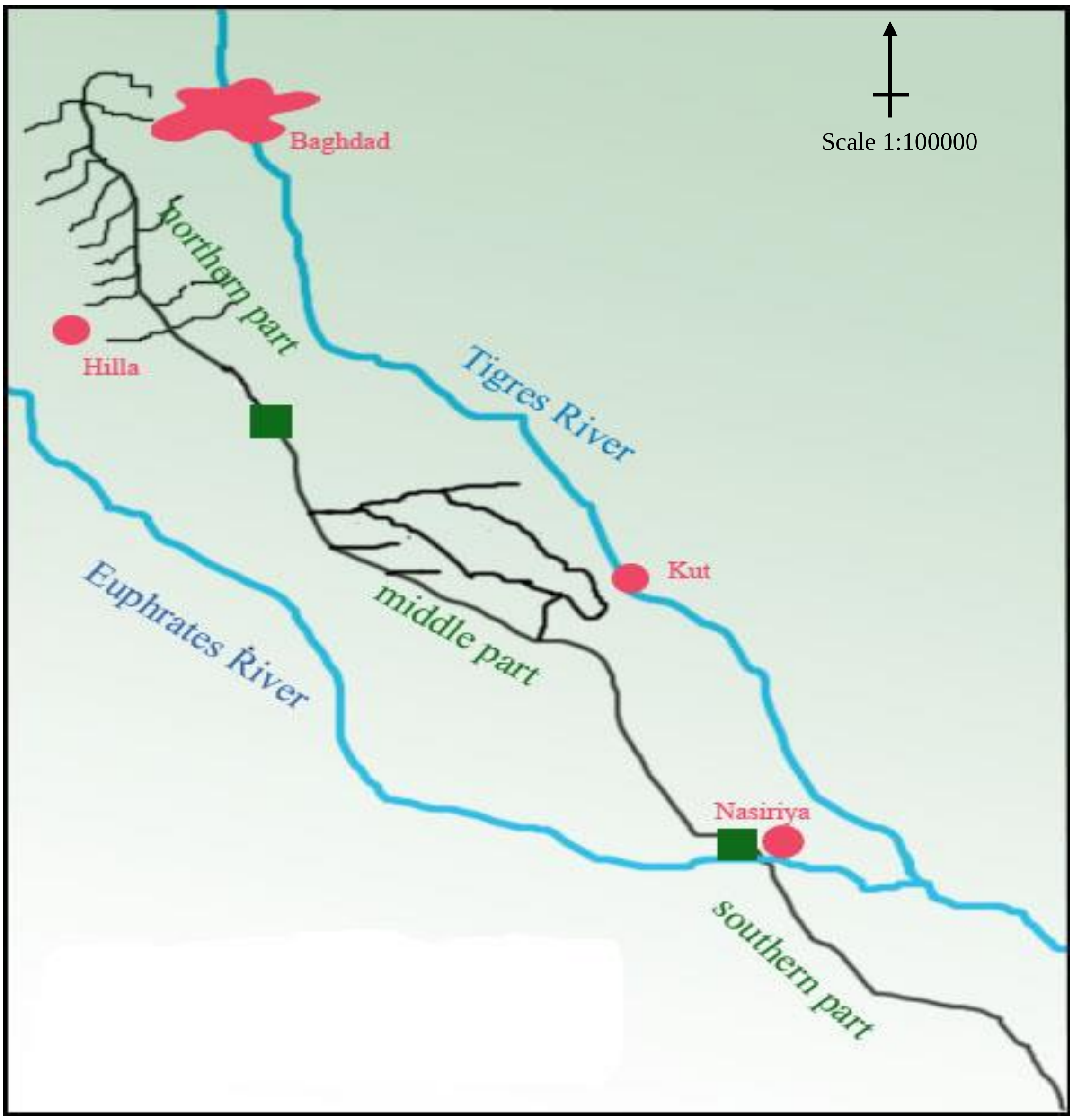


Fig. (3-1-a): a General map of the Main Outfall Drain [BWRD,(2006)]

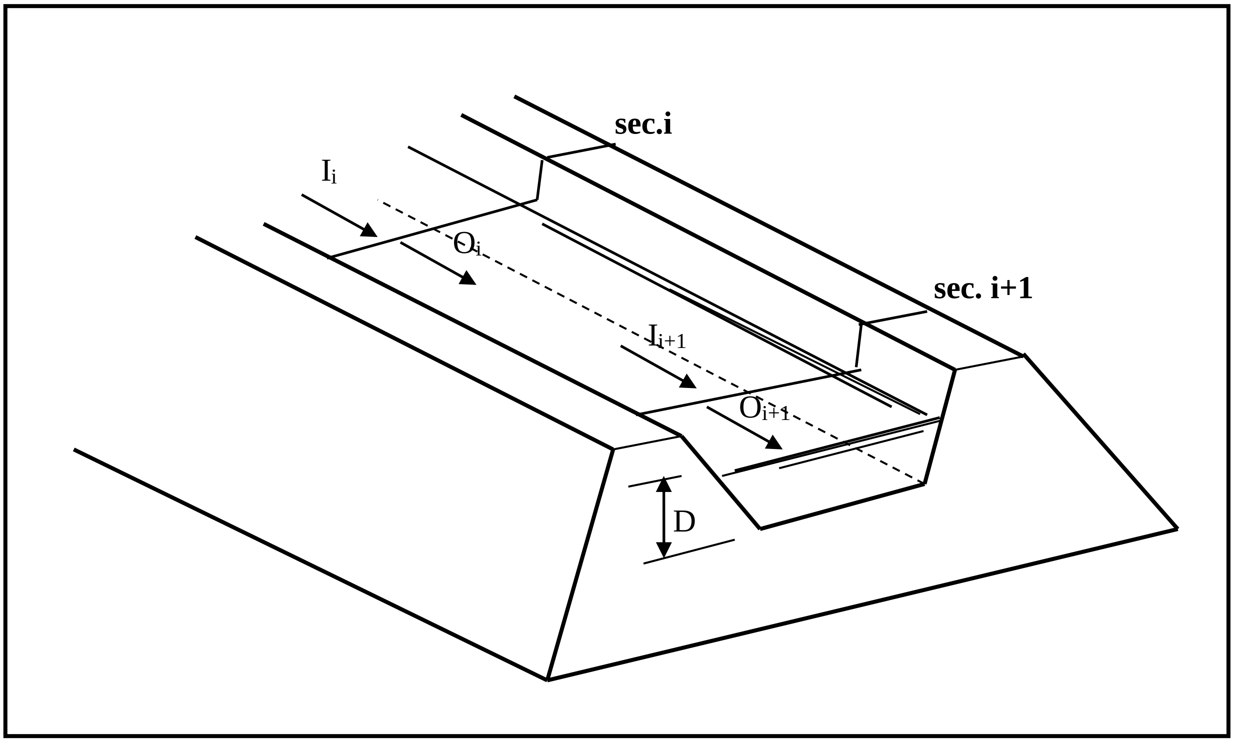


Fig.(3-1-b):Typical cross-section of MOD

Table (3-1): Hydraulic design of the first part of MOD[BWRD,(2006]

Distance (Km)	D (m)	B (m)	S (cm/Km)
0.000	4.43	7.80	6.5
16.650	4.49	8.00	6.9
23.000	4.32	3.00	7.2
41.730	4.08	3.00	9.2
55.980	4.29	3.00	9.0
66.930	4.39	3.00	9.0
75.750	4.47	3.00	9.0
84.950	4.50	5.40	9.0
101.600	4.50	6.00	8.1
128.650	4.50	13.00	8.1
141.800	4.50	13.80	8.1
167.165	4.50	20.40	8.1

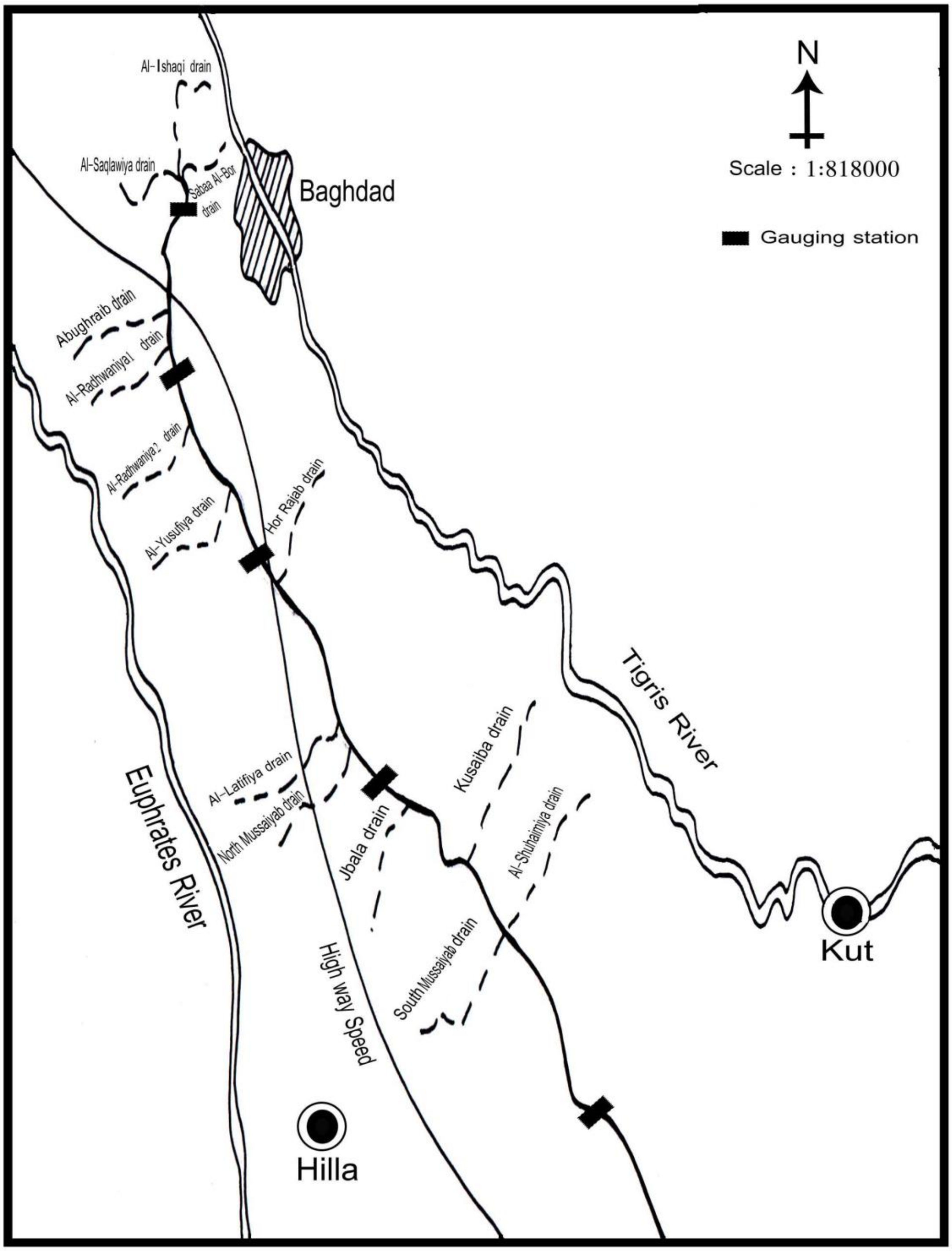


Fig. (3-1-c): Location map of the first part of MOD [BWRD, (2006)]

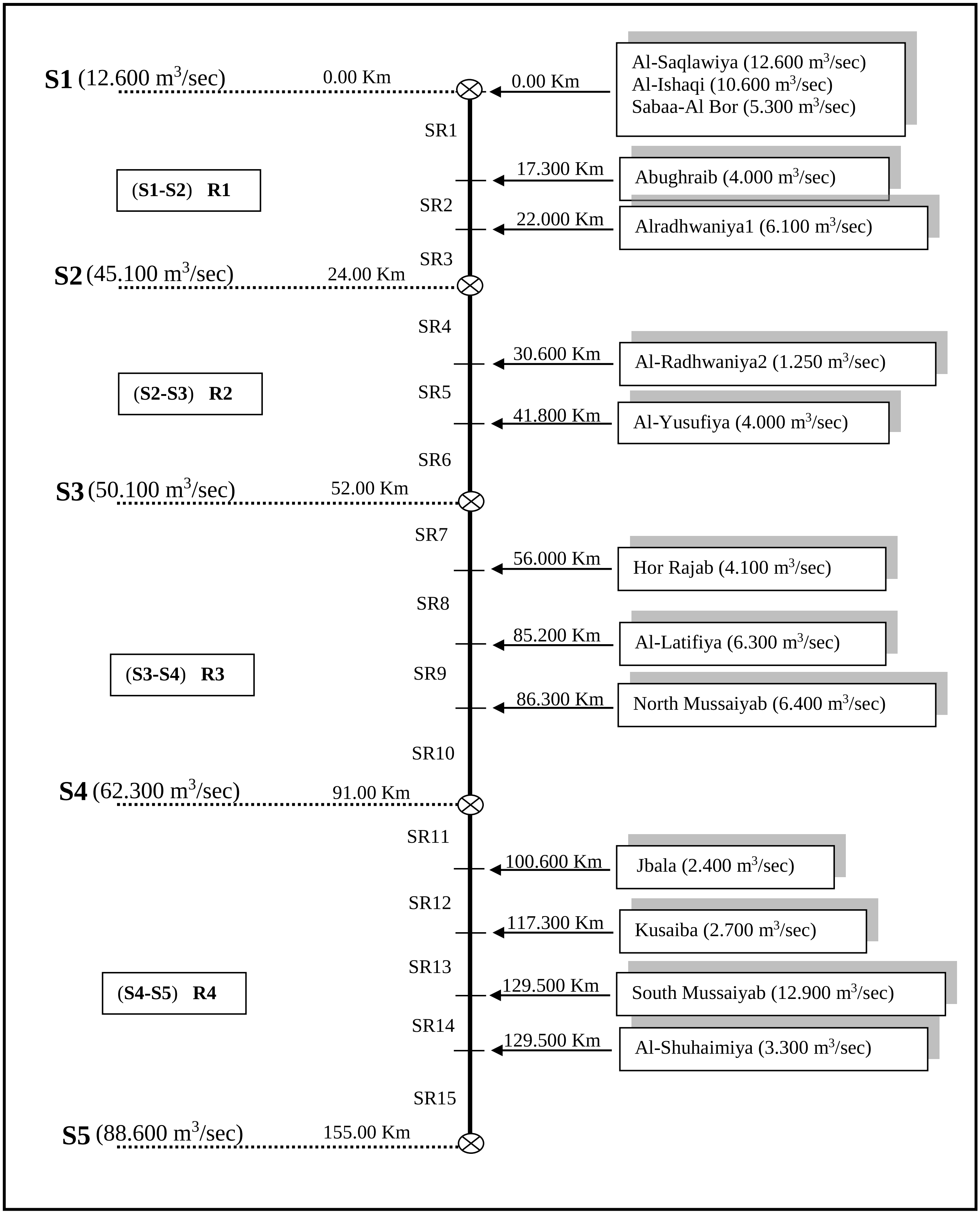


Fig.(3-1-d): Schematic representation of the constituents of the first part of MOD
[HINTS]:(1) The sketch is out of scale.
(2) The figures of the flow denote the design discharge.

3-4-3 : The data available

A major obstacle in hydrologic analyses, including this research, is obtaining a reliable sufficient data. On several contacts with the respective Iraqi authorities, the only data that were available are:

1-Monthly discharge for each drain and gauging station of the first part of the Main Outfall Drain from the year 1996 to the year 2001[**BWRD**, **(2006)**].{Given in (A1) in Appendix-A}.

2-The actually cultivated areas for the summer and winter seasons for the year 2001 [**BAD, (2006)**].{Given in (A2) in Appendix-A}

The data available are the average monthly discharges whereas the daily measurements are not available. The routing process requires observed hydrographs at the selected times ($\mathbf{t_i}$), probably daily or sometimes even at shorter times, depending on the nature of the routed wave. To take use of the available monthly data, the following assumptions and computation procedure have been adopted:

A- Changing monthly discharge into daily measurement.

B- The discharge will be taken (m^3/hr) instead of (m^3/sec).

To perform item (A) hereinbefore, the variation of the discharge was assumed linear for all days of each month. To achieve the requirements of item (B), a similar approach has been followed for each day of the month.

To perform the routing for each subreach, the following has been made to arrive at the runoff that resemble the recorded one at the end of the subreach (which will be that of the beginning of the next subreach), starting from (S1) (as an example) and working for (R1) which involves the subreaches SR1, SR2, and SR3:

1- The runoff at (S1) and (S2) are already defined (as actually recorded).

2- The base flow between (S1) and (S2) would be:

$$\Delta Q = Q_{S2} - [Q_{S1} + (Q_{Ab.} + Q_{Ra.})] \qquad (3\text{-}12)$$

where:

Q_{S2}= discharge at gauging station 2 (L^3/T);

Q_{S1} = discharge at gauging station 1 (L^3/T);

Q_{Ab} = discharge at Abughraib drain (L^3/T);

Q_{Ra} = discharge at Radhwaniya1 drain (L^3/T).

3- The base flow was assumed to come linearly to the reach; consequently, the outflow of SR1 before Ab. Is calculated by Eq.(3-9). The inflow of SR2 is:

$$I_{SR2} = O_{SR1} + Q_{Ab} + \Delta Q \; \frac{L_1}{L} \qquad (3\text{-}13)$$

where:

I_{SR2} = inflow of subreach 2 (L^3/T);

O_{SR1} = outflow of subreach 1(L^3/T);

Q_{Ab} = discharge at Abughraib drain (L^3/T);

L_1 = length of subreach 1 (L^3);

L = length of reach 1 (L^3).

3-5 : Calibration and verification of the mathematical model

3-5-1 : The calibration process

The calibration means the right choice of the model parameters, (K, x and Δt) which affect the stability and convergence of the solution. This may be achieved through empirically-established relationships, e.g., Eqs. (3-14) and (3-15) [**Dooge et al.,(1986)**]:

$$\mathbf{K = \frac{0.6L}{V_\circ}} \quad (3\text{-}14)$$

$$\mathbf{x = 0.5 - 0.3\left(1 - \frac{4F^2}{9}\right)\frac{y_\circ}{S_\circ L}} \quad (3\text{-}15)$$

where:

K= travel time, (T);
x= routing coefficient, (dimensionless);
$\mathbf{V_\circ}$= average velocity, (L/T);
F= Froude number, (dimensionless);
$\mathbf{y_\circ}$= full flow depth, (L);
$\mathbf{S_\circ}$= slope of the channel bottom, (L/L);
L= length of the reach, (L).

The graphical procedure is usable when observed hydrographs are available for both the upstream and downstream ends of the considered channel reach.

From Eqs.(3-2) and (3-8), one obtains:

$$\mathbf{K = \frac{0.5\Delta t[(I_{i+1} + I_i) - (O_{i+1} + O_i)]}{x(I_{i+1} - I_i) + (1 - x)(O_{i+1} - O_i)}} \quad (3\text{-}16)$$

The computed values of the numerator [$\mathbf{0.5\Delta t[(I_{i+1} + I_i) - (O_{i+1} + O_i)]}$] and denominator [$\mathbf{x(I_{i+1} - I_i) + (1 - x)(O_{i+1} + O_i)}$] of Eq.(3-16) are plotted for each time interval, with the numerator on the vertical axis and the denominator on the horizontal axis. This usually produces a graph in the form of a loop. The value of (x) that produces a loop closest to a single line is taken to be the correct value for the reach and (K), according to Eq.(3-16), is equal to the slope of the line.[**Chow et al., (1988)**]

In the absence of any previous determination of the routing coefficients of MOD in general and its first part in particular, the trial-and-error approach would be the only practical solution to this dilemma. The graphical solution or Eqs. (3-14) and (3-15) may be used in this respect.

However, because the available data are limited, the usual long and routine trial-and-error approach has been adopted. The following has been followed in this respect:

1- The value of (K) is taken nearly equal to the flow time (Ft), i.e., the time for the flow to pass between two consecutive considered locations. Accordingly, trial values of (K) of (2-20 hrs) have been adopted for use.

2- Values of (x) in the range (0.1-0.4), step (0.05) have been tried.

3- As suggested by **Viessman et al., (1989)**, the values of (Δt) can be estimated by satisfying Eq.(3-17):

$$\mathbf{2Kx \le \Delta t \le K} \qquad (3\text{-}17)$$

In running the trial-and-error calculations, a total of (5488) trials have been performed, using [(19) values of (K), (7) values of (x), and (20) values of (Δt)]. The number of trials for R1 is (343), for R2 is (343), for R3 is (2401), and for R4 is (2401).

Starting from (S1), the calculations are performed for SR1, and the results are transferred to the following subreach, and so on, until attaining the end at (S5).

Two statistics has been used in analyzing the results, namely:

1- The percent deviation, PD, defined as:

$$\mathbf{PD\,\% = \frac{Q_O - Q_C}{Q_O} \times 100} \qquad (3\text{-}18)$$

2- Mean absolute deviation, MAD, defined as:

$$\mathbf{MAD\,\% = \frac{\sum_{i=1}^{n} \left| PD_i\,\% \right|}{n}} \qquad (3\text{-}19)$$

The results indicated that if the value of (Δt) is equal to (K), the difference between Q_O and Q_C will be high, (PD%=2.01 at S_2, PD%=1.50 at

S_3, PD%=3.00 at S_4, and PD%=3.65 at S_5,). With (Δt) less than (K), the difference between observed outflow and calculated outflow will be less. The best value of (Δt) has been found to be of ($\Delta t = 0.5K$) for each subreach, that is, the values of (K) are (2, 4, 6, 8, 12, 16, 18, and20 hours), whereas values of (Δt) will be (1, 2, 3, 4, 6, 8, 9, and 10 hours), respectively.

Sample results are given in Table (3-2) after reaching the values with the best reference statistics. The final values adopted for use in this research are listed in Table (3-3) . Tables (3-4) and (B-1) and (B-2) show sample calculations for (January -2001) at S2, S3, and S4, respectively. Table (B-3) shows sample calculations for the first eight days of January, 2001. Figures (3-2) to (3-5) show the hydrographs of outflow at stations of the first part of MOD. Tables (3-5) to (3-8) show the observed and calculated outflow at S2,S3,S4 and S5 for the first part of MOD for the year 2001. Maximum PD% were during the whole tested year (+1.02) to (-0.02) whereas the MAD% was (1.2%).

3-5-2 : The verification process

The verification of a mathematical model means that the model used is a replica of the prototype. For this goal a set of observed hydrographs which are not used in the calibration of the model are used with the verification model.

The data of the calendar year 1996 shall be used in the verification process because that year is characterized by relatively high inflows due to a denser rainfall together with a noticeable increase in cultivated lands . Tables (3-9) and (B-4) to (B-6) show sample calculations of outflow at S2, S3, S4, and S5, respectively , for the year1996. The tables indicate that the respective (PD%) is so small that the verification process could be viewed as successful. Maximum PD% were during the whole tested year (+1.8)to(-0.5) whereas the MAD% was (2.01%). The verification process has been set as a computer program, written in visual basic. The flow chart of the routing program is given in Fig. (3-6).

Table (3-2): Sample results of Muskingum parameters for the subreaches of the first part of MOD by the trial calculation No.(133)

SR No.	SR name	L (m)	T (hr)	K (hr)	x	Δt (hr)	PD%
1	S1-Ab.	17300	16.01	16	0.10	8	
2	Ab.-Ra.1	4700	4.42	4	0.40	2	
3	Ra.1-S2	2000	1.85	2	0.40	1	1.18
4	S2- Ra.2	6600	4.48	4	0.10	2	
5	Ra.2-Yu.	11200	7.77	8	0.40	4	
6	Yu.-S3	10200	6.48	6	0.40	3	0.99
7	S3-HR.	4000	3.70	4	0.10	2	
8	HR.-La.	29200	20.27	20	0.10	10	
9	La.-NM.	1100	1.51	2	0.10	1	
10	NM.-S4	4700	4.35	4	0.10	2	1.77
11	S4-Jb.	9600	6.46	6	0.40	3	
12	Jb.-Ku.	16700	11.59	12	0.40	6	
13	Ku.-SM. and Sh.	12200	8.47	8	0.40	4	
14	SM and Sh.-S5	25500	17.70	18	0.40	9	2.62

Table (3-3): Adopted values of Muskingum parameters for subreaches of the first part of MOD

SR No.	SR name	L (m)	T (hr)	K (hr)	x	Δt (hr)	PD%
1	S1-Ab.	17300	16.01	16	0.15	8	
2	Ab.-Ra.1	4700	4.42	4	0.40	2	
3	Ra.1-S2	2000	1.85	2	0.20	1	0.91
4	S2- Ra.2	6600	4.48	4	0.15	2	
5	Ra.2-Yu.	11200	7.77	8	0.40	4	
6	Yu.-S3	10200	6.48	6	0.30	3	0.98
7	S3-HR.	4000	3.70	4	0.15	2	
8	HR.-La.	29200	20.27	20	0.15	10	
9	La.-NM.	1100	1.51	2	0.15	1	
10	NM.-S4	4700	4.35	4	0.15	2	1.72
11	S4-Jb.	9600	6.46	6	0.10	3	
12	Jb.-Ku.	16700	11.59	12	0.10	6	
13	Ku.-SM. and Sh.	12200	8.47	8	0.10	4	
14	SM and Sh.-S5	25500	17.70	18	0.10	9	2.54

Table (3-4) Sample results of calculation of the Muskingum model at S2 of the first part of MOD in days of January for the year 2001

(hr)	Q_{O2} (m^3/hr)	Q_{C2} (m^3/hr)	PD_2 %	(hr)	Q_{O2} (m^3/hr)	Q_{C2} (m^3/hr)	PD_2 %
Date : 1/1/2001				**Date : 5/1/2001**			
0	**106241**	**106241**	**0.00**				
1	106258	106255	0.00	1	107930	107848	0.08
2	106275	106269	0.01	2	107948	107865	0.08
3	106293	106283	0.01	3	107965	107883	0.08
4	106310	106297	0.01	4	107983	107900	0.08
5	106328	106311	0.02	5	108000	107918	0.08
6	106345	106325	0.02	6	108017	107935	0.08
7	106363	106339	0.02	7	108035	107952	0.08
8	106380	106353	0.03	8	108052	107970	0.08
9	106397	106367	0.03	9	108070	107987	0.08
10	106415	106381	0.03	10	108087	108005	0.08
11	106432	106395	0.04	11	108105	108022	0.08
12	106450	106409	0.04	12	108122	108040	0.08
13	106467	106423	0.04	13	108139	108057	0.08
14	106485	106437	0.04	14	108157	108074	0.08
15	106502	106451	0.05	15	108174	108092	0.08
16	106519	106465	0.05	16	108192	108109	0.08
17	106537	106479	0.05	17	108209	108127	0.08
18	106554	106493	0.06	18	108226	108144	0.08
19	106572	106507	0.06	19	108244	108161	0.08
20	106589	106521	0.06	20	108261	108179	0.08
21	106606	106535	0.07	21	108279	108196	0.08
22	106624	106549	0.07	22	108296	108214	0.08
23	106641	106563	0.07	23	108314	108231	0.08
24	**106659**	**106577**	**0.08**	**24**	**108331**	**108249**	**0.08**
Date : 2/1/2001				**Date : 6/1/2001**			
1	106676	106594	0.08	1	108348	108266	0.08
2	106694	106611	0.08	2	108366	108283	0.08
3	106711	106629	0.08	3	108383	108301	0.08
4	106728	106646	0.08	4	108401	108318	0.08
5	106746	106664	0.08	5	108418	108336	0.08
6	106763	106681	0.08	6	108435	108353	0.08

Table (3-4)-continued

7	106781	106699	0.08	7	108453	108370	0.08
8	106798	106716	0.08	8	108470	108388	0.08
9	106815	106733	0.08	9	108488	108405	0.08
10	106833	106751	0.08	10	108505	108423	0.08
11	106850	106768	0.08	11	108523	108440	0.08
12	106868	106786	0.08	12	108540	108458	0.08
13	106885	106803	0.08	13	108557	108475	0.08
14	106903	106820	0.08	14	108575	108492	0.08
15	106920	106838	0.08	15	108592	108510	0.08
16	106937	106855	0.08	16	108610	108527	0.08
17	106955	106873	0.08	17	108627	108545	0.08
18	106972	106890	0.08	18	108645	108562	0.08
19	106990	106907	0.08	19	108662	108580	0.08
20	107007	106925	0.08	20	108679	108597	0.08
21	107025	106942	0.08	21	108697	108614	0.08
22	107042	106960	0.08	22	108714	108632	0.08
23	107059	106977	0.08	23	108732	108649	0.08
24	**107077**	**106994**	**0.08**	**24**	**108749**	**108667**	**0.08**
Date : 3/1/2001				**Date : 7/1/2001**			
1	107094	107012	0.08	1	108766	108684	0.08
2	107112	107029	0.08	2	108784	108701	0.08
3	107129	107047	0.08	3	108801	108719	0.08
4	107146	107064	0.08	4	108819	108736	0.08
5	107164	107082	0.08	5	108836	108754	0.08
6	107181	107099	0.08	6	108854	108771	0.08
7	107199	107116	0.08	7	108871	108789	0.08
8	107216	107134	0.08	8	108888	108806	0.08
9	107234	107151	0.08	9	108906	108823	0.08
10	107251	107169	0.08	10	108923	108841	0.08
11	107268	107186	0.08	11	108941	108858	0.08
12	107286	107203	0.08	12	108958	108876	0.08
13	107303	107221	0.08	13	108975	108893	0.08
14	107321	107238	0.08	14	108993	108910	0.08
15	107338	107256	0.08	15	109010	108928	0.08

Table (3-4)-continued

16	107355	107273	0.08	16	109028	108945	0.08
17	107373	107291	0.08	17	109045	108963	0.08
18	107390	107308	0.08	18	109063	108980	0.08
19	107408	107325	0.08	19	109080	108998	0.08
20	107425	107343	0.08	20	109097	109015	0.08
21	107443	107360	0.08	21	109115	109032	0.08
22	107460	107378	0.08	22	109132	109050	0.08
23	107477	107395	0.08	23	109150	109067	0.08
24	**107495**	**107412**	**0.08**	**24**	**109167**	**109085**	**0.08**
Date : 4/1/2001				**Date : 8/1/2001**			
1	107512	107430	0.08	1	109185	109102	0.08
2	107530	107447	0.08	2	109202	109120	0.08
3	107547	107465	0.08	3	109219	109137	0.08
4	107565	107482	0.08	4	109237	109154	0.08
5	107582	107500	0.08	5	109254	109172	0.08
6	107599	107517	0.08	6	109272	109189	0.08
7	107617	107534	0.08	7	109289	109207	0.08
8	107634	107552	0.08	8	109306	109224	0.08
9	107652	107569	0.08	9	109324	109241	0.08
10	107669	107587	0.08	10	109341	109259	0.08
11	107686	107604	0.08	11	109359	109276	0.08
12	107704	107621	0.08	12	109376	109294	0.08
13	107721	107639	0.08	13	109394	109311	0.08
14	107739	107656	0.08	14	109411	109329	0.08
15	107756	107674	0.08	15	109428	109346	0.08
16	107774	107691	0.08	16	109446	109363	0.08
17	107791	107709	0.08	17	109463	109381	0.08
18	107808	107726	0.08	18	109481	109398	0.08
19	107826	107743	0.08	19	109498	109416	0.08
20	107843	107761	0.08	20	109515	109433	0.08
21	107861	107778	0.08	21	109533	109451	0.08
22	107878	107796	0.08	22	109550	109468	0.08
23	107895	107813	0.08	23	109568	109485	0.08
24	**107913**	**107831**	**0.08**	**24**	**108348**	**108266**	**0.08**

Table (3- 5): Observed and calculated outflow at S2 of the first part of MOD for the year 2001

Month	Q_O (1000 m^3/hr)	Q_C (1000 m^3/hr)
Jan	107	107
Feb	113	118
Mar	134	137
Apr	129	133
May	88	90
Jun	71	73
Jul	75	75
Aug	83	83
Sep	93	90
Oct	96	96
Nov	101	91
Dec	162	157

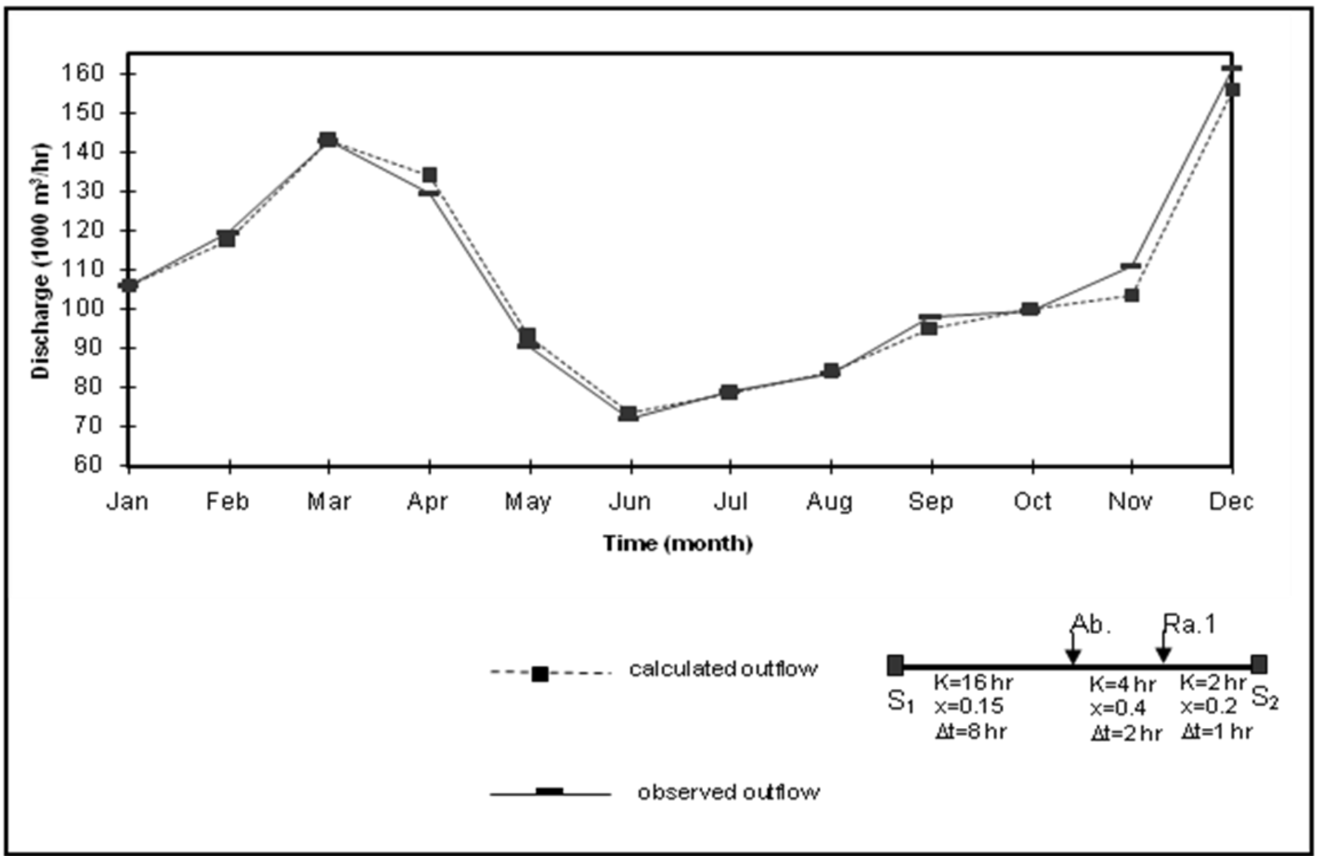


Fig. (3-2): Hydrographs of outflow at S2 of the first part of MOD for the year 2001

Table (3- 6): Observed and calculated outflow at S3 of the first part of MOD for the year 2001

Month	Q_O (1000 m^3/hr)	Q_C (1000 m^3/hr)
Jan	148	148
Feb	150	150
Mar	154	154
Apr	150	146
May	115	106
Jun	96	88
Jul	88	88
Aug	90	90
Sep	100	100
Oct	115	115
Nov	130	140
Dec	210	190

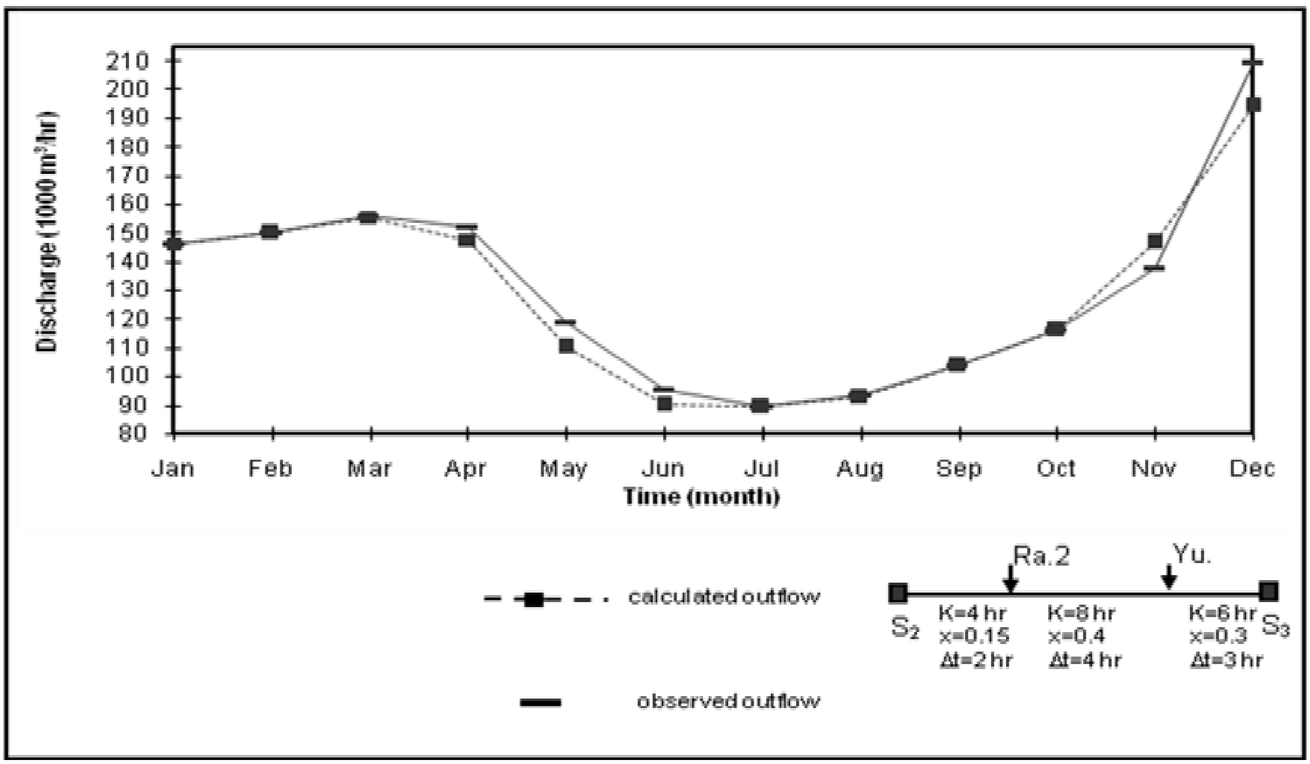


Fig. (3-3): Hydrographs of outflow at S3 of the first part of MOD for the year 2001

Table (3- 7): Observed and calculated outflow at S4 of the first part of MOD for the year 2001

Month	Q_O (1000 m^3/hr)	Q_C (1000 m^3/hr)
Jan	286	286
Feb	299	300
Mar	285	284
Apr	270	269
May	278	275
Jun	220	208
Jul	211	218
Aug	223	223
Sep	225	225
Oct	242	241
Nov	251	250
Dec	154	253

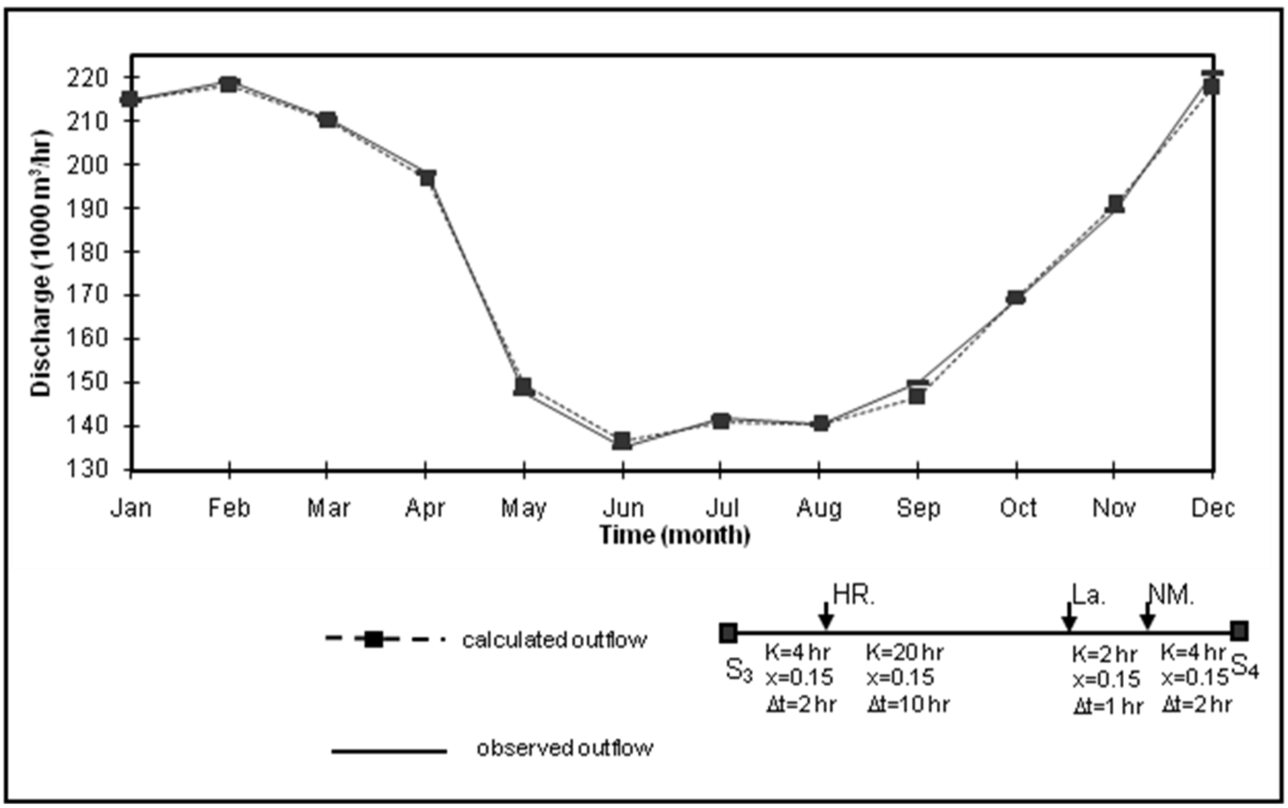


Fig. (3-4): Hydrographs of outflow at S4 of the first part of MOD for the year 2001

Table (3- 8): Observed and calculated outflow at S5 of the first part of MOD for the year 2001

Month	Q_O (1000 m^3/hr)	Q_C (1000 m^3/hr)
Jan	286	286
Feb	299	300
Mar	285	284
Apr	270	269
May	278	275
Jun	220	208
Jul	211	218
Aug	223	223
Sep	225	225
Oct	242	241
Nov	251	250
Dec	154	253

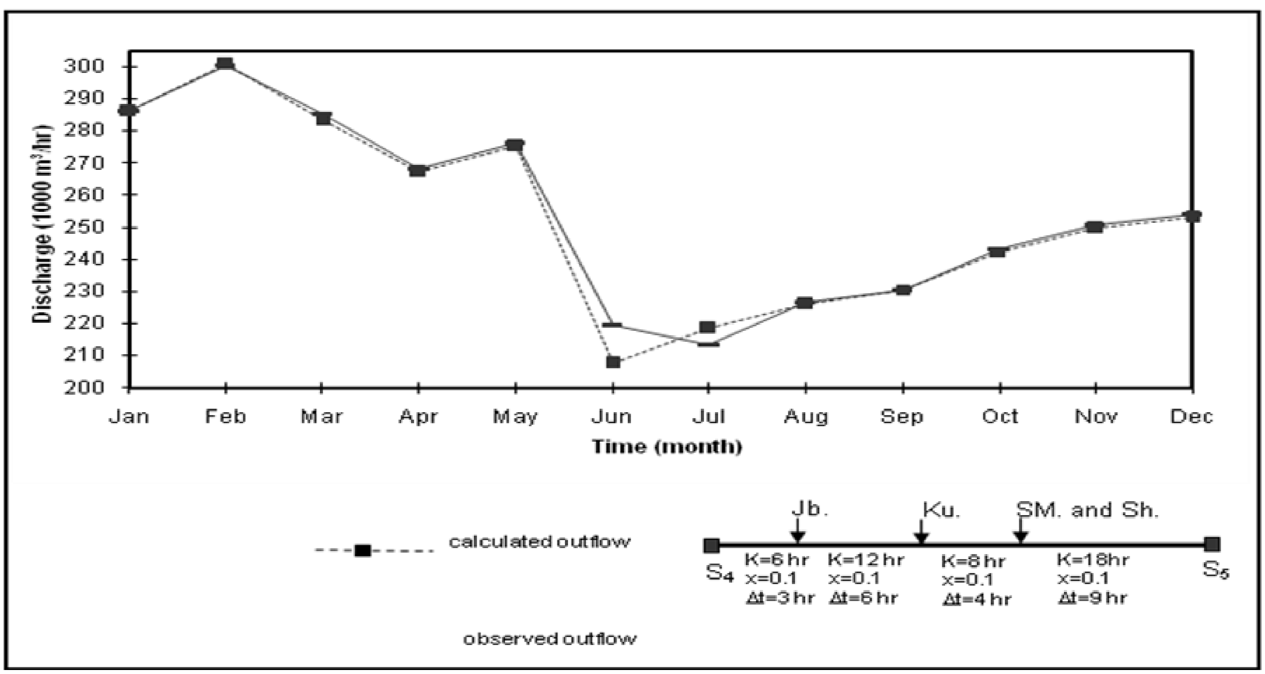


Fig. (3-5): Hydrographs of outflow at S5 of the first part of MOD for the year 2001

Table (3-9) Sample results of calculation of the Muskingum model at S2 of the first part of MOD in days of January for the year 1996

(hr)	Q_{O2} (m^3/hr)	Q_{C2} (m^3/hr)	PD_2%	(hr)	Q_{O2} (m^3/hr)	Q_{C2} (m^3/hr)	PD_2 %
Date : 1/1/1996				**Date : 5/1/1996**			
0	**130325**	**130325**	**0.00**				
1	130791	130870	-0.06	1	136409	135949	0.34
2	131255	131334	-0.06	2	135533	135073	0.34
3	131720	131799	-0.06	3	134657	134197	0.34
4	132184	132263	-0.06	4	133781	133321	0.34
5	132649	132728	-0.06	5	132905	132445	0.35
6	133113	133192	-0.06	6	132029	131569	0.35
7	133578	133657	-0.06	7	131153	130693	0.35
8	134042	134121	-0.06	8	130277	129817	0.35
9	134507	134586	-0.06	9	129401	128941	0.36
10	134971	135050	-0.06	10	128525	128065	0.36
11	135436	135515	-0.06	11	127649	127189	0.36
12	135900	135979	-0.06	12	126773	126313	0.36
13	136365	136444	-0.06	13	125897	125437	0.37
14	136829	136908	-0.06	14	125021	124561	0.37
15	137294	137373	-0.06	15	124145	123685	0.37
16	137758	137837	-0.06	16	123269	122809	0.37
17	138223	138302	-0.06	17	122393	121933	0.38
18	138687	138766	-0.06	18	121517	121057	0.38
19	139152	139231	-0.06	19	120641	120181	0.38
20	139616	139695	-0.06	20	119765	119305	0.38
21	140081	140160	-0.06	21	118889	118429	0.39
22	140546	140625	-0.06	22	118013	117553	0.39
23	141010	141089	-0.06	23	117137	116677	0.39
24	**141475**	**141554**	**-0.06**	**24**	**116781**	**116395**	**0.33**
Date : 2/1/1996				**Date : 6/1/1996**			
1	141939	142018	-0.06	1	116532	116140	0.34
2	142404	142483	-0.06	2	116278	115884	0.34
3	142868	142947	-0.06	3	116023	115629	0.34
4	143333	143412	-0.06	4	115767	115373	0.34
5	143797	143876	-0.05	5	115512	115118	0.34
6	144262	144341	-0.05	6	115256	114862	0.34

Table (3-8)-continued

7	144487	144471	0.01	7	115001	114607	0.34
8	144616	144587	0.02	8	114745	114351	0.34
9	144734	144702	0.02	9	114490	114096	0.34
10	144850	144818	0.02	10	114234	113840	0.34
11	144966	144934	0.02	11	113979	113585	0.35
12	145082	145049	0.02	12	113723	113329	0.35
13	145197	145165	0.02	13	113468	113074	0.35
14	145313	145281	0.02	14	113212	112818	0.35
15	145429	145397	0.02	15	112957	112563	0.35
16	145545	145512	0.02	16	112701	112307	0.35
17	145660	145628	0.02	17	112446	112052	0.35
18	145776	145744	0.02	18	112190	111796	0.35
19	145892	145859	0.02	19	111935	111541	0.35
20	146007	145975	0.02	20	111679	111285	0.35
21	146123	146091	0.02	21	111424	111030	0.35
22	146239	146207	0.02	22	111168	110775	0.35
23	146355	146322	0.02	23	110913	110519	0.36
24	**146470**	**146438**	**0.02**	**24**	**110657**	**110264**	**0.36**
Date : 3/1/1996				**Date : 7/1/1996**			
1	146586	146554	0.02	1	110402	110008	0.36
2	146702	146669	0.02	2	110147	109753	0.36
3	146817	146785	0.02	3	109891	109497	0.36
4	146933	146901	0.02	4	109636	109242	0.36
5	147049	147017	0.02	5	109380	108986	0.36
6	147165	147132	0.02	6	109125	108731	0.36
7	147280	147248	0.02	7	108748	108640	0.10
8	147396	147364	0.02	8	108584	108556	0.03
9	147512	147479	0.02	9	108487	108472	0.01
10	147627	147595	0.02	10	108401	108388	0.01
11	147514	147455	0.04	11	108317	108304	0.01
12	147348	147304	0.03	12	108233	108220	0.01
13	147195	147153	0.03	13	108149	108136	0.01
14	147043	147002	0.03	14	108065	108052	0.01
15	146892	146851	0.03	15	107981	107968	0.01

Table (3-8)-continued							
16	146741	146700	0.03	16	107897	107884	0.01
17	146590	146550	0.03	17	107813	107800	0.01
18	146439	146399	0.03	18	107729	107716	0.01
19	146288	146248	0.03	19	107645	107632	0.01
20	146137	146097	0.03	20	107561	107548	0.01
21	145986	145946	0.03	21	107477	107464	0.01
22	145835	145795	0.03	22	107393	107380	0.01
23	145684	145644	0.03	23	107309	107296	0.01
24	**145534**	**145493**	**0.03**	**24**	**107225**	**107212**	**0.01**
Date : 4/1/1996				**Date : 8/1/19961**			
1	145383	145342	0.03	1	107141	107128	0.01
2	145232	145191	0.03	2	107057	107044	0.01
3	145081	145040	0.03	3	106973	106960	0.01
4	144930	144889	0.03	4	106889	106876	0.01
5	144779	144738	0.03	5	106805	106792	0.01
6	144628	144587	0.03	6	106721	106708	0.01
7	144477	144436	0.03	7	106637	106624	0.01
8	144326	144285	0.03	8	106553	106540	0.01
9	144175	144134	0.03	9	106469	106456	0.01
10	144024	143983	0.03	10	106385	106372	0.01
11	143873	143832	0.03	11	106301	106288	0.01
12	143722	143681	0.03	12	106217	106204	0.01
13	143571	143530	0.03	13	105824	106300	-0.45
14	143420	143379	0.03	14	105791	106405	-0.58
15	143269	143228	0.03	15	105873	106509	-0.60
16	143118	143077	0.03	16	105974	106614	-0.60
17	142967	142926	0.03	17	106078	106718	-0.60
18	142457	142081	0.26	18	106182	106823	-0.60
19	141651	141205	0.32	19	106287	106927	-0.60
20	140786	140329	0.33	20	106391	107032	-0.60
21	139912	139453	0.33	21	106496	107136	-0.60
22	139037	138577	0.33	22	106601	107241	-0.60
23	138161	137701	0.33	23	106705	107345	-0.60
24	**137285**	**136825**	**0.34**	**24**	**106715**	**107360**	**-0.06**

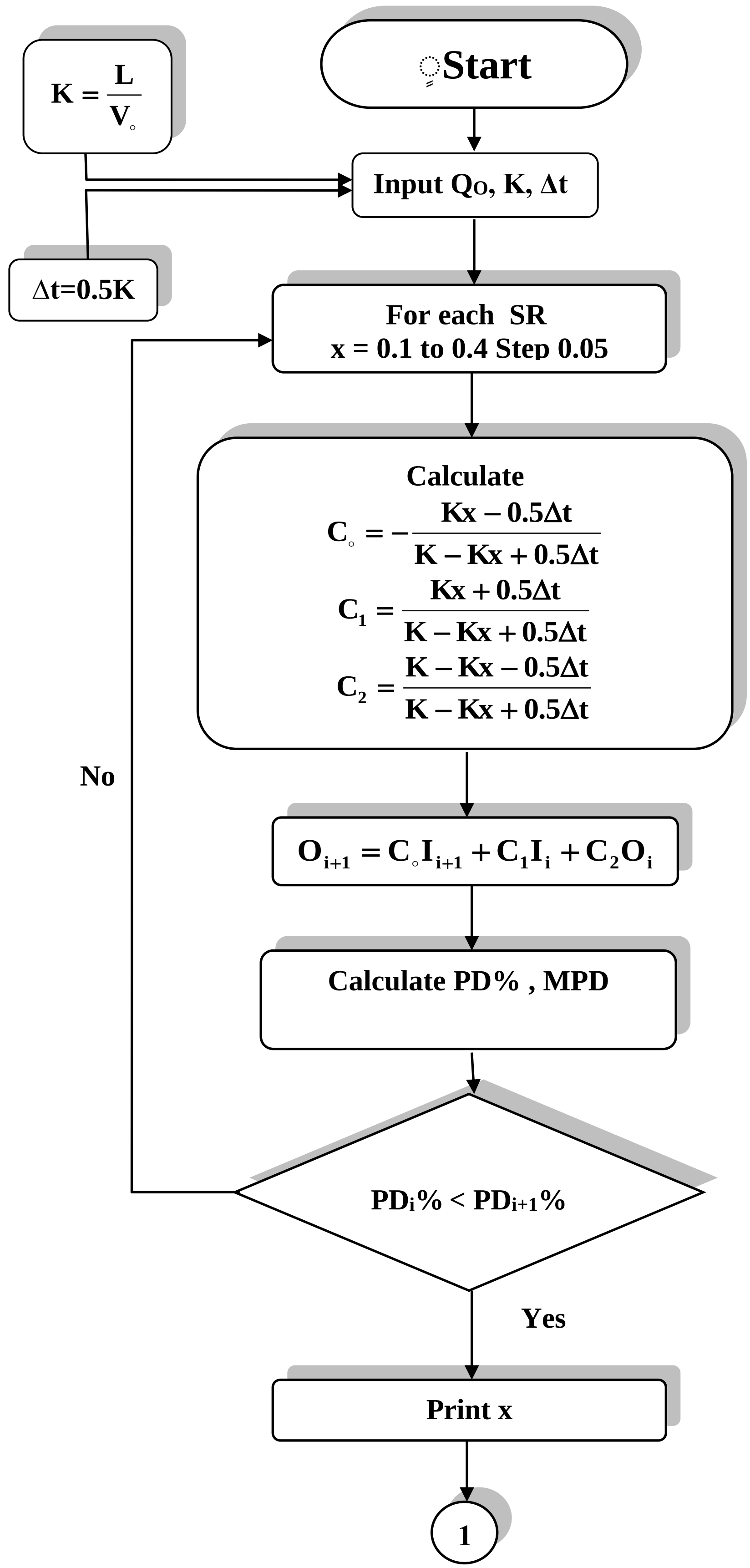


Figure (3-6): Flow chart of the routing program

CHAPTER FOUR

APPLICATIONS AND RESULTS

4-1 : The adopted operation scenarios

The officially allocated water to the involved agricultural projects was not set available to the researcher. Some hypothetical agricultural scenarios will be considered for the analyses. These scenarios are:

1- Considering the present state of the first part of MOD, i.e., operating the model for the existing agricultural density for the involved agricultural projects.

2- Considering an overall agricultural density of (50%).

3- Ditto for (100%).

4- Ditto for (125%).

5- Ditto for (160%). This cultivation intensity is mostly used as the maximum one throughout the areas in the middle of Iraq [**DGED, (2006)**].

4-2 : Calculated outflows

Table (4-1) and Fig. (4-1) show the calculated outflow at the key points of the first part of MOD for the month October and for the five selected operation scenarios, together with the respective minimum and maximum design values. Tables (C-1) through (C-11) and Figs. (C-1) through (C-11) show the aforementioned results for the months November through September, respectively.

Table (4-1): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for October

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	28444	65434	56888	71110	91021	71820	143640
Ab.	34384	77238	68768	85960	110029	81000	162000
Ra.1	43720	95947	87440	109300	139904	81000	162000
S2	45284	98080	90568	113210	144909	81000	162000
Ra.2	49228	102317	98456	123070	157530	90000	180000
Yu.	68862	125423	137724	172155	220358	90000	180000
S3	69743	127040	139486	174358	223178	90000	180000
HR.	71330	135471	142660	178325	228256	122000	244000
La.	78293	162665	156586	195733	250538	122000	244000
NM.	79632	168765	159264	199080	254822	122000	244000
S4	81543	181495	163086	203858	260938	122000	244000
Jb.	82582	183952	165164	206455	264262	159500	319000
Ku.	90470	201493	180940	226175	289504	159500	319000
SM. and Sh.	117977	245952	235954	294943	377526	159500	319000
S5	127966	266265	255932	319915	409491	159500	319000

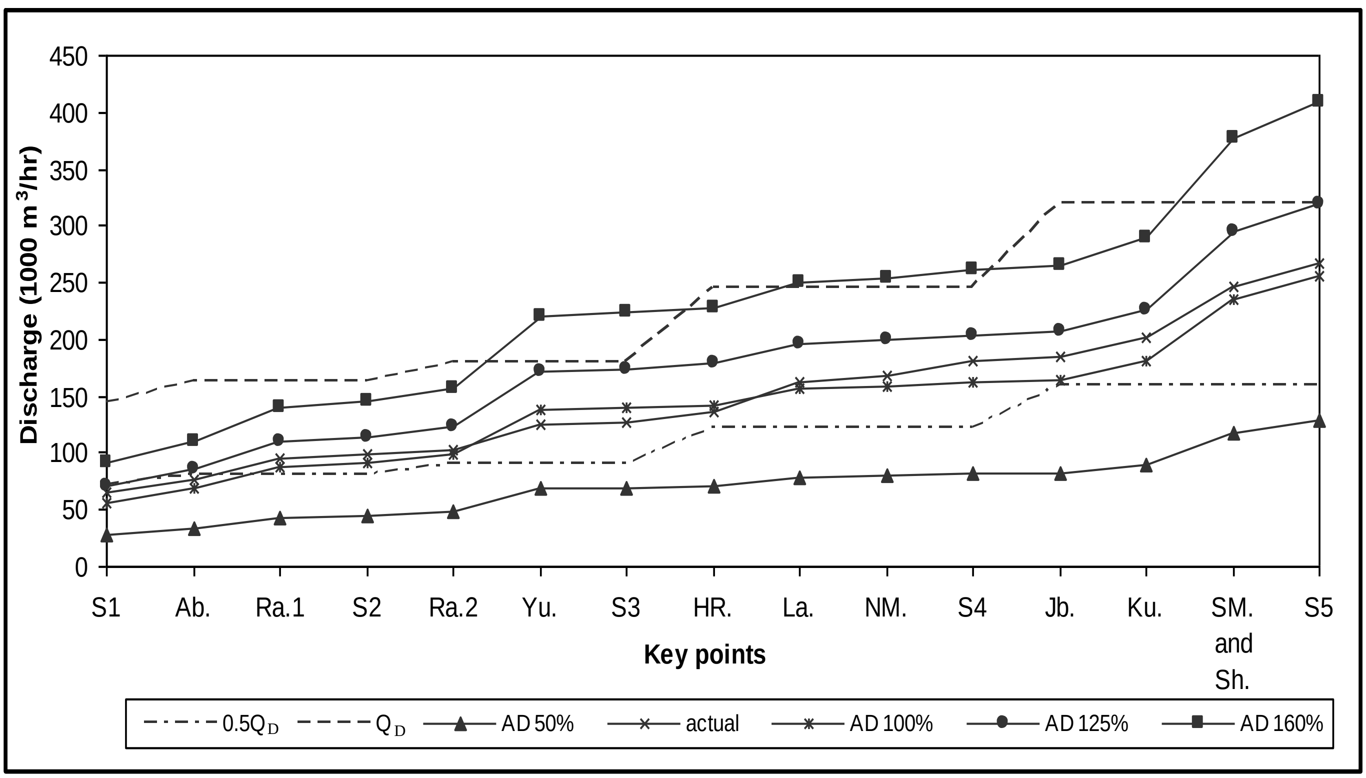


Figure (4-1): Hydrographs at the key points of the first part of MOD for the adopted scenarios for October

4-3 : Optimizing the operation of the first part of MOD

4-3-1 : The optimization process

An optimization process constitutes formulating the respective optimization mathematical model, and then solving the formulated model by an appropriate solution procedure.

In general, the case to be optimized could be ‘static’ (a single-stage problem) or ‘dynamic’ (a multi-stage problem). The former is commonly covered by linear programming or non-linear programming, as the case enforces. The latter is covered by dynamic programming. Most problems involved in the operation of water resources systems are of the dynamic type.

The formulation of an optimization problem implies identifying the objective of the optimization process, defining the controlling decision variables, setting the objective in a mathematical form, and setting the constraints imposed on the system as functions (equalities and / or inequalities) of the decision variables.

The following items discuss the optimization process for the chosen case study.

4-3-2 : Formulation of the optimization model

[A] : **The objective** :

MOD was designed according to some design criteria (which, unfortunately, have not been available to the researcher). The course of the case study (the first part of MOD) is virtually the course of some previously existing drains which has been developed to accommodate the new design.

The agricultural projects served by the case study are still in a developing stage. The General Scheme of Water Resources and Land Development in Iraq have allocated certain annual shares of water to every existing and proposed agricultural project in Iraq, including those served by the case study. Again, unfortunately, such allocations have not been available to the researcher despite the several personal connections with the different respective governmental authorities.

The objective of the optimization process in this research is to take the full use of the case study such that it will indicate the minimum (if not null) over design and under design.

Based on what is mentioned hereinbefore, only hypothetical, practically-feasible, operation scenarios would be possible [as given in Item (4-1)].

[B] : **<u>The decision variables</u>** :

The decision variables are those parameters in the studied process which are controllable or partially controllable.

In this research, the decision variables are the discharges of the case study at the considered basic key points, namely, (S1), (S2), (S3), (S4), and (S5).

[C] : **<u>The objective function</u>** :

The objective function is the objective, set in a mathematical form as a function of the specified decision variables and of the involved state variables, if any. It reflects the effectiveness of the taken decisions on the performance of the system. This formulated objective function is to be optimized (maximized for expected benefits or returns, or minimized for expected costs or penalties).

Denoting the design discharge of MOD at the j-th key point as (Q_{Dj}). In this research, it is assumed that the value ($0.5Q_{Dj}$) is the neutral value. The objective function, set in monetary terms, (MU), is formulated as follows:

$$\begin{cases} 1 - \text{If } \mathbf{Q_{ij} = 0.5\,Q_{Dj}} & \text{then : } \mathbf{F_{ij} = 0} \\ 2 - \text{If } \mathbf{Q_{ij} < 0.5\,Q_{Dj}} & \text{then : } \mathbf{F_{ij} = \alpha\,[Q_{ij} - 0.5\,Q_{Dj}]} \\ 3 - \text{If } \mathbf{0.5\,Q_{Dj} < Q_{ij} \leq Q_{Dj}} & \text{then : } \mathbf{F_{ij} = \beta\,[Q_{ij} - 0.5\,Q_{Dj}]} \\ 4 - \text{If } \mathbf{Q_{ij} > Q_{Dj}} & \text{then: } \mathbf{F_{ij} = \gamma\,[Q_{Dj} - Q_{ij}]} \end{cases} \quad (4\text{-}1)$$

The aforementioned possible stages of the flow in the case study are illustrated schematically in Fig.(4-2).

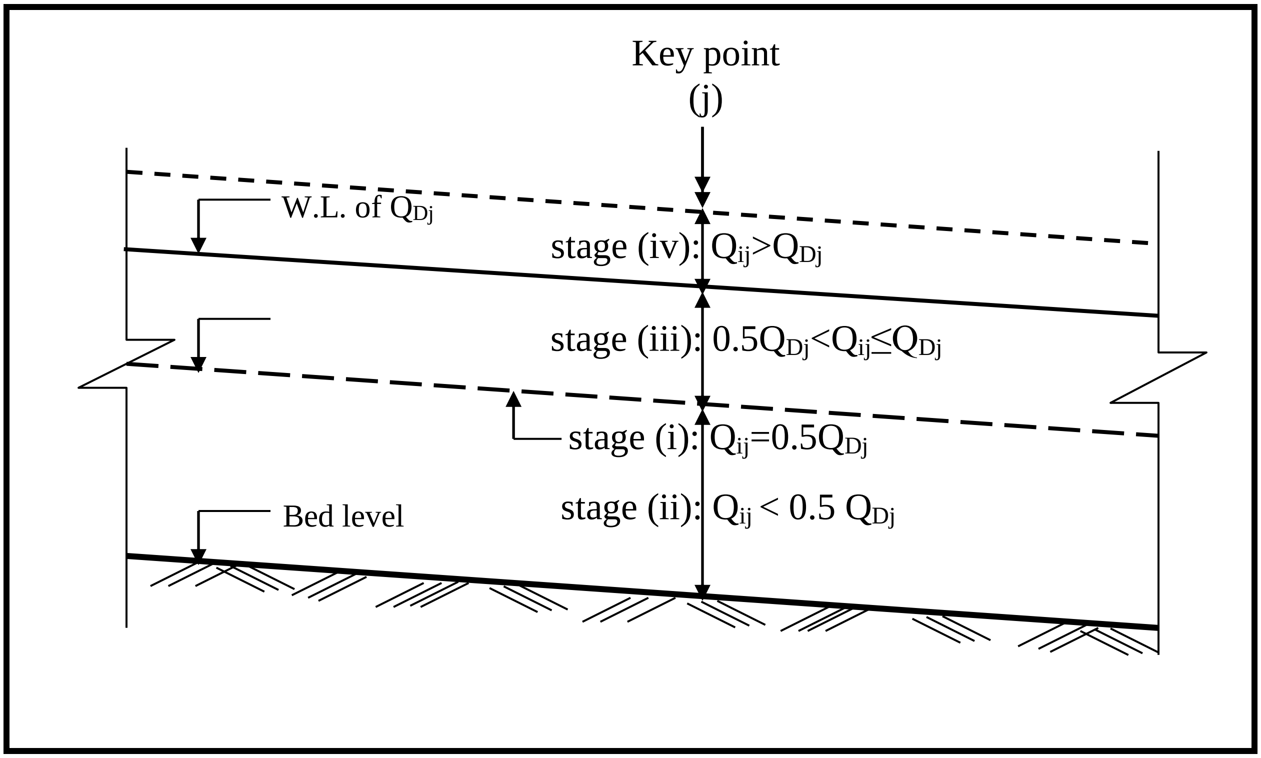


Fig. (4-2): Schematic illustration of the possible stage of flow at the j-th key point in the case study

5 – In the absence of a better, rigid criterion for the agricultural density for the agricultural projects served by the case study, it is assumed in this research that the standard level of the total agricultural density for all the agricultural projects served by the case study, denoted as (SAD_k donum) for the k-th agricultural project, is (100%), [(55%) in winter cropping, (35%) in summer cropping, and (5%*2) orchards (perennials)].

It is obvious that under normal circumstances, an increase in the agricultural density (which is virtually an increase in the cropped area) will result in a respective increase in the return, and vice versa. However, such a change (increase or decrease) in the cropped area will produce a corresponding change in the quantity of water draining from that project. This, in turn, will affect the flow in the respective part (s) of the case study, which may result in transferring the flow at the respective key points from one stage of the four flow stages mentioned hereinbefore to another.

While the monetary effect of the change of flow is taken care of in the respective objective function, the monetary evaluation of the change of the cropped area is handled through the following:

For the k-th agricultural project with a proposed area of (A_k donum) to be cultivated:

$$\mathbf{F_k = \delta\ [A_k - SAD_k]} \qquad (4\text{-}2)$$

6 – The total objective function (TF) to be optimized will be:

$$\mathbf{Max.TF = \sum_{i=1}^{12}\sum_{j=1}^{5} F_{ij} + \sum_{k=1}^{14} F_k} \qquad (4\text{-}3)$$

where: (i) denotes a month in a water year; (i=1, 2, …, 12);

(j) denotes a basic key point on the case study; (j=1, 2, …, 5);

(k) denotes an agricultural project served by the case study;

(k=1, 2, …, 14);

(α), (β), and (γ) are the monetary evaluations ($MU/m^3/hr$) of the respective flow case;

(δ) is the monetary evaluation of the net unit annual return from changed cropped area, (MU/donum);

In this research, the following values for the evaluation parameters (α), (β), (γ), and (δ) have been arbitrarily adopted:

α=1.5 $MU/m^3/hr$

β=1.0 $MU/m^3/hr$

γ=3.0 $MU/m^3/hr$

δ=2.0 MU/donum

[D] : **<u>The constraints imposed on the system</u>** :

Beside some other specific constraints, two categories of constraints are common in most, if not all, problems involved in water resources engineering; this research is not an exception. Those constraints are: The mass-balance (continuity) constraints and the capacity constraints.

The mass-balance constraint is given by Eq. (3-1). It has been the keystone in the formulation of the routing model, Eq. (3-9). Consequently, this constraint is implicitly satisfied whenever and wherever the routing model is run.

The capacity constraint in this research refers to the capacity of the case study to accommodate the incoming drainage water. This has been interpreted by the four flow stages mentioned in the preceding item. The violation of this constraint is evaluated in monetary terms. Thus, this constraint has been considered implicitly in the optimization model.

4-3-3 : Solving the formulated optimization model

The earliest procedure for solving an optimization problem formulated as a dynamic-programming model is what is sometimes called the 'conventional dynamic programming'. It involves discretizing the involved state and decision variables, each into a number of values that fits the problem under considerations, listing all the possible alternative combinations of the state and decision variables, discarding the infeasible combinations, i.e., those which may be considered impractical because they violate some compulsory constraints imposed on the system, solving for the remaining (feasible) combinations, one at a time, and then carrying the results from one stage to the next, starting at the initial stage and ending at the last stage.

The conventional dynamic programming is very simple in its presentation and gives straightforward answers. Nevertheless, it is the crudest among the known solution procedures and the most involved if the dimensions of the problem (number of state and decision variables to be considered at each stage) are high. Obtaining a final solution in some of such cases becomes impossible even with the use of a very capable modern computer; this is due to the very very huge requirements of computer storage and running time; a state commonly termed as the 'curse of dimensionality'.

Of the several researches performed to overcome the curse of dimensionality, the one of [**Heidari et al., (1971)**] and their Discrete Differential Dynamic Programming, DDDP, still stands at the front.

Despite the general disadvantages of the conventional dynamic programming, the nature of the optimization problem (as a whole) in this research and the way in which the involved parameters have been discretized (as previously outlined) made the conventional dynamic programming to be an acceptable procedure for the aimed solution. Consequently, the conventional dynamic programming has been adopted for use in this research. The flow chart of the solution of the optimization model is given in Fig. (4-3).

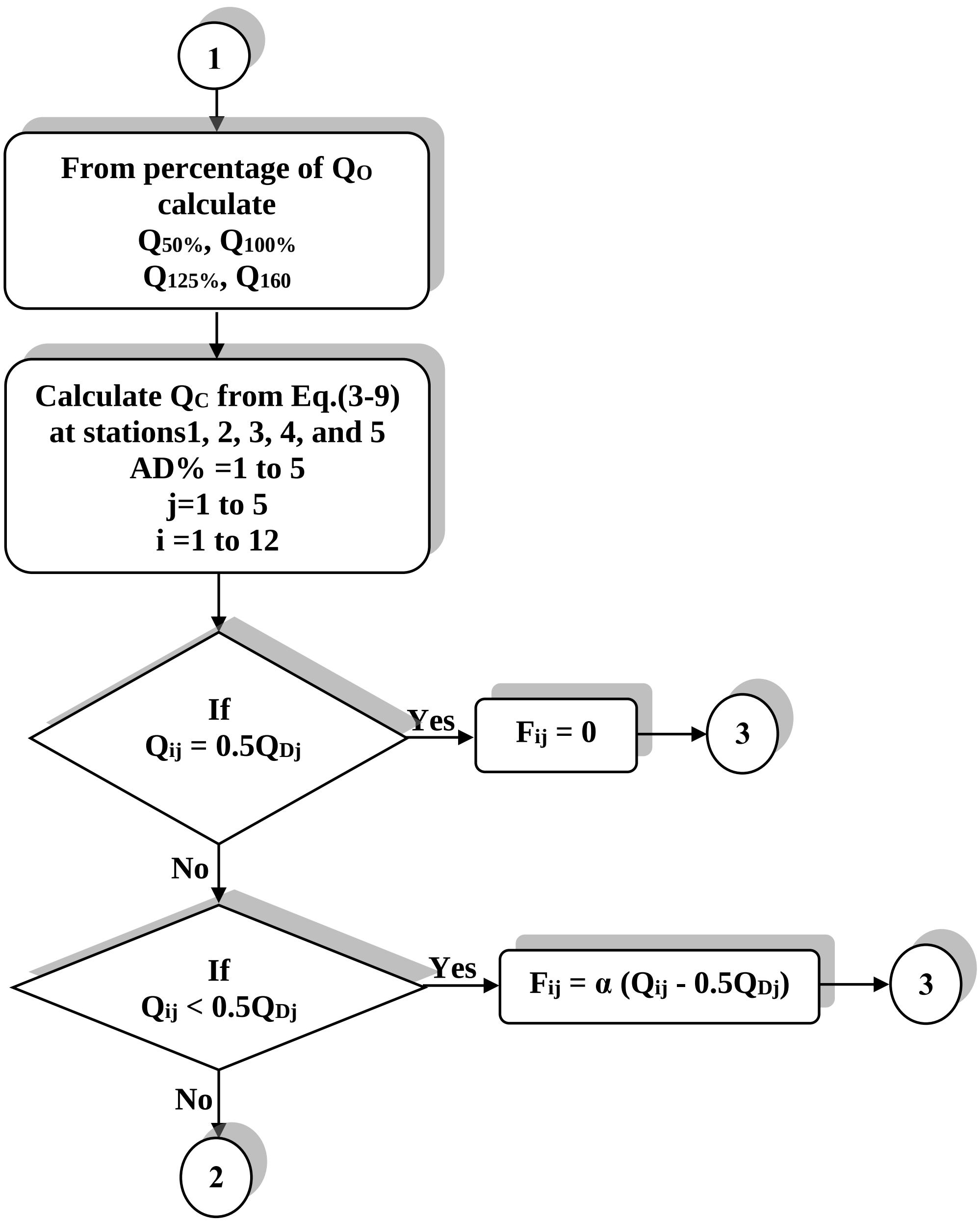
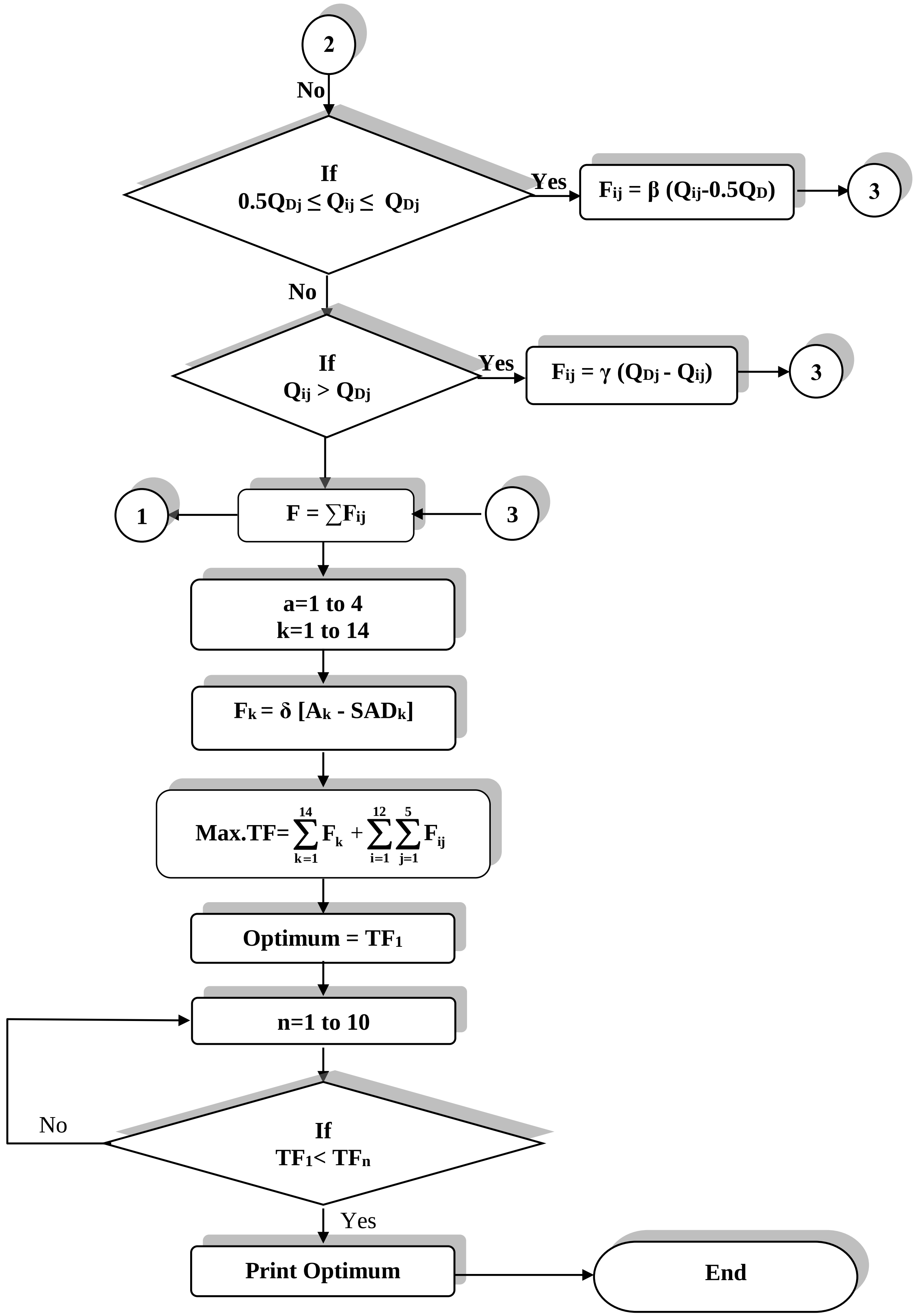


Figure (4-3): Flow chart of the optimization program



[Figure (4-3)-continued]

4-3-4 : Results of the optimization process

Recalling that (F_{ij}) denotes the comparative value of the partial objective function (in monetary units MU) that reflects the state of the flow at the j-th key point on the case study during the i-th month of a water year. Tables (4-2) through (4-6) show the values of (F_{ij}) according to the five adopted operation scenarios, namely, (AD=actual), (AD=50%), (AD=100%), (AD=125%), and (AD=160%), respectively.

Table (4-2): Values (MU) of the partial objective function (F_{ij}) for the first operation scenarios (AD =actual)

Month (i) \ Key point (j)		S1	S2	S3	S4	S5	$\sum F_{ij}$
1	Oct.	-9579	17080	37040	59495	106765	210801
2	Nov.	-5339	39235	50021	73907	121402	279226
3	Dec.	8715	45903	75400	103200	141300	374518
4	Jan	4041	24840	63360	103720	137500	333461
5	Feb	13587	36476	67239	108268	156182	381752
6	Mar.	29755	59850	73035	101057	116205	379902
7	Apr.	24451	54523	69561	90330	128500	367365
8	May	1253	21720	31996	53362	52900	161231
9	Jun.	-26888	-3048	12112	26523	40736	49435
10	Jul.	-33923	-7800	6690	27458	54583	47008
11	Aug.	-29670	581	15961	32374	78684	97930
12	Sep.	-19923	7868	32066	43484	104665	168160
$\sum F_{ij}$	(MU)	-43518	297228	534481	823178	1239422	2850791
Total value of the objective function concerning the state of the flow : F=2850791							

Table (4-3): Values (MU) of the partial objective function (F_{ij}) for the second operation scenarios (AD=50%)

Month (i) \ Key point (j)		S1	S2	S3	S4	S5	$\sum F_{ij}$
1	Oct.	-65064	-53574	-30386	-60686	-47301	-257010
2	Nov.	-62598	-35988	-14940	-48161	-36303	-197990
3	Dec.	-57678	-37949	-2655	-22499	-21308	-142088
4	Jan	-55329	-48201	-5244	-27779	-24206	-160758
5	Feb	-46499	-40143	-1802	-26025	-10169	-124637
6	Mar.	-38198	-23955	2229	-27542	-40209	-127674
7	Apr.	-41672	-27644	-2736	-36431	-30972	-139454
8	May	-57093	-50360	-36689	-67050	-87774	-298965
9	Jun.	-70829	-66810	-50738	-85085	-96449	-369909
10	Jul.	-74553	-69006	-55553	-81333	-88719	-369164
11	Aug.	-72648	-65003	-49374	-80988	-69873	-337886
12	Sep.	-68744	-59955	-35592	-71510	-48882	-284682
$\sum F_{ij}$ (MU)		-710903	-578586	-283478	-635085	-602163	-2810214
Total value of the objective function concerning the state of the flow : F=-2810214							

Table (4-4): Values (MU) of the partial objective function (F_{ij}) for the third operation scenarios (AD=100%)

Month (i) \ Key point (j)		S1	S2	S3	S4	S5	$\sum F_{ij}$
1	Oct.	-22398	9568	49486	41086	96432	174174
2	Nov.	-17466	33016	62325	57786	111096	246757
3	Dec.	-7626	30402	86460	92002	131090	332328
4	Jan	-2928	16732	83008	84962	127226	309000
5	Feb	9822	27476	87598	88019	145942	358857
6	Mar.	20890	49060	13374	85278	105888	247742
7	Apr.	16258	44142	86352	73426	118204	338382
8	May	-6456	13854	41082	32600	42468	123548
9	Jun.	-33927	-12120	22350	8554	30902	15759
10	Jul.	-41376	-16512	15930	13556	41208	12806
11	Aug.	-37566	-8505	24168	14016	66336	58449
12	Sep.	-29757	1060	42544	26654	94324	134825
$\sum F_{ij}$ (MU)		-152530	188173	587929	617939	1111116	2352627
Total value of the objective function concerning the state of the flow : F=2352627							

Table (4-5): Values (MU) of the partial objective function (F_{ij}) for the fourth operation scenarios (AD=125%)

Month (i) \ Key point (j)		S1	S2	S3	S4	S5	$\sum F_{ij}$
1	Oct.	-1065	32210	84358	81858	-2745	194616
2	Nov.	3400	61520	-60300	102733	-57735	49618
3	Dec.	11600	58253	-121725	-70509	-132714	-255095
4	Jan	15515	41165	-108780	-44109	-118224	-214433
5	Feb	30233	54595	-125994	-48750	-188409	-278325
6	Mar.	44068	-1725	-151719	-45294	-38205	-192875
7	Apr.	38278	75428	-121320	-849	-84390	-92853
8	May	12575	37568	73853	71250	92960	288206
9	Jun.	-15475	10150	50438	41193	78503	164808
10	Jul.	-24787	6490	42413	47445	91385	162945
11	Aug.	-20025	13163	52710	48020	122795	216663
12	Sep.	-10263	21575	75680	63818	157780	308590
$\sum F_{ij}$ (MU)		84053	410392	-310386	246806	-78999	351866
Total value of the objective function concerning the state of the flow : F=351866							

Table (4-6): Values (MU) of the partial objective function (F_{ij}) for the fifth operation scenarios (AD=160%)

Month (i) \ Key point (j)		S1	S2	S3	S4	S5	$\sum F_{ij}$
1	Oct.	19201	63909	-129534	-50814	-271473	-368711
2	Nov.	24462	-61278	-228384	-130974	-341862	-738036
3	Dec.	34958	-48729	-307008	-295209	-437832	-1053820
4	Jan	39969	75371	-290439	-261417	-419286	-855802
5	Feb	58807	-34686	-312471	-276087	-509121	-1073558
6	Mar.	-14088	-138288	-345399	-262935	-316863	-1077573
7	Apr.	69105	-114681	-306489	-206046	-375978	-934089
8	May	36206	70766	-89193	-10080	-12447	-4748
9	Jun.	6903	35672	89760	86886	145143	364364
10	Jul.	-1563	30987	79488	94890	-6399	197403
11	Aug.	3022	39528	-8007	95626	-127014	3155
12	Sep.	11351	50296	-96210	115846	-261354	-180071
$\sum F_{ij}$ (MU)		288333	-31133	-1943886	-1100314	-2934486	-5721486
Total value of the objective function concerning the state of the flow : F=-5721486							

The aforementioned results are summarized schematically for the considered five key points in Figs. (4-4) through (4-8), respectively.

On considering the design discharge at the key point (j), i.e., Q_{Dj}, as the perfect value, and ($0.5Q_{Dj}$) as the neutral one, i.e., the relative zero value, the value of (F_{ij}) would be (+ve) (i.e., gain), when ($0.5\ Q_{Dj} < Q_{ij} \leq Q_{Dj}$) whereas they would be (-ve) (i.e., loss) elsewhere.

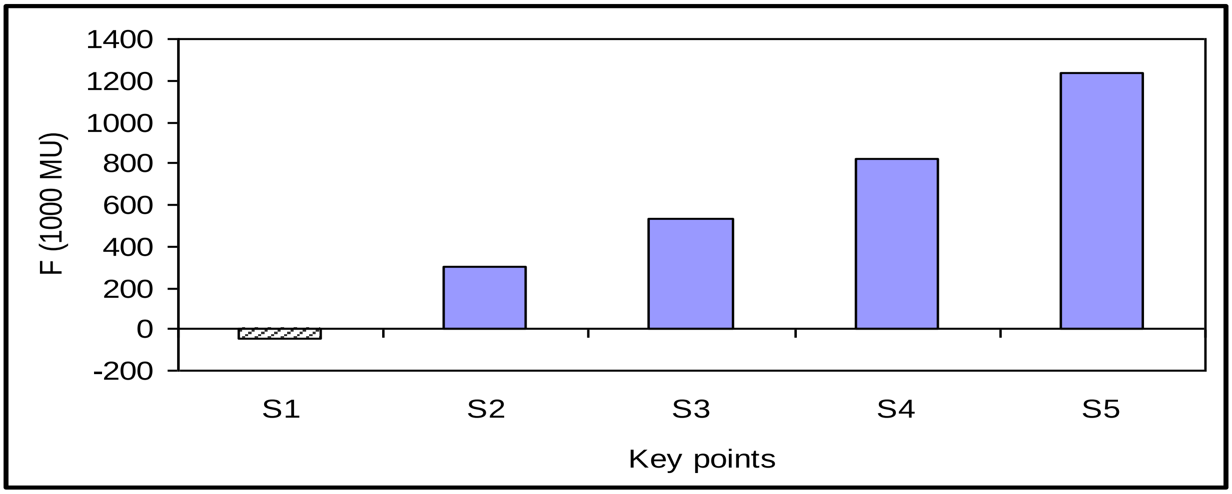


Fig. (4-4): Annual objective function concerning the flow state for (AD=actual)

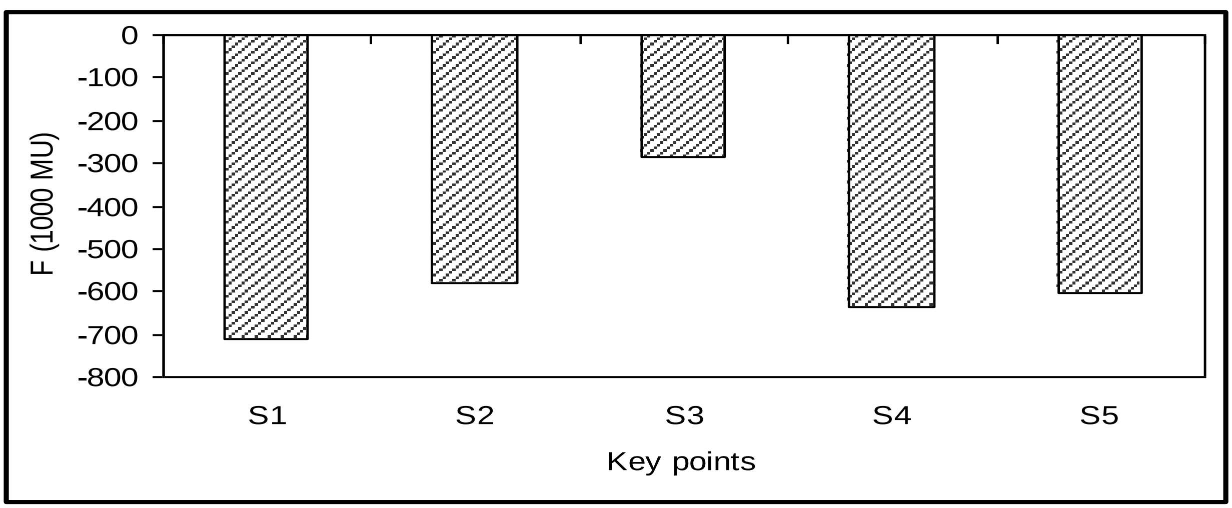


Fig. (4-5): Annual objective function concerning the flow state for (AD=50%)

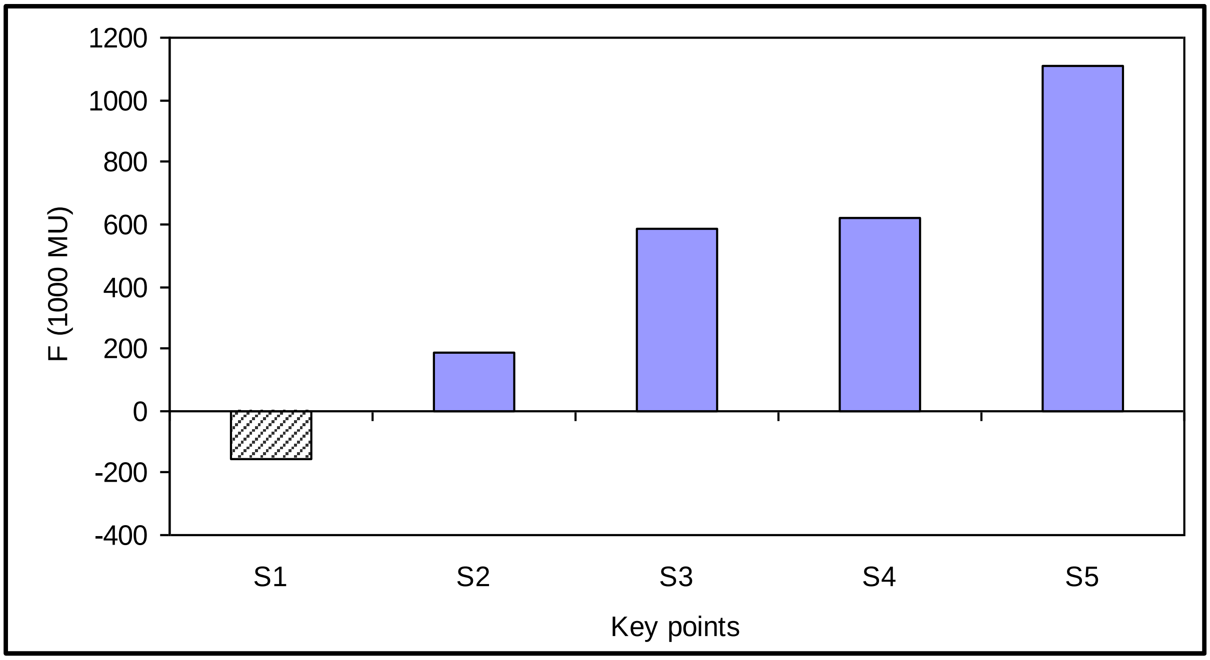


Fig. (4-6): Annual objective function concerning the flow state for (AD=100%)

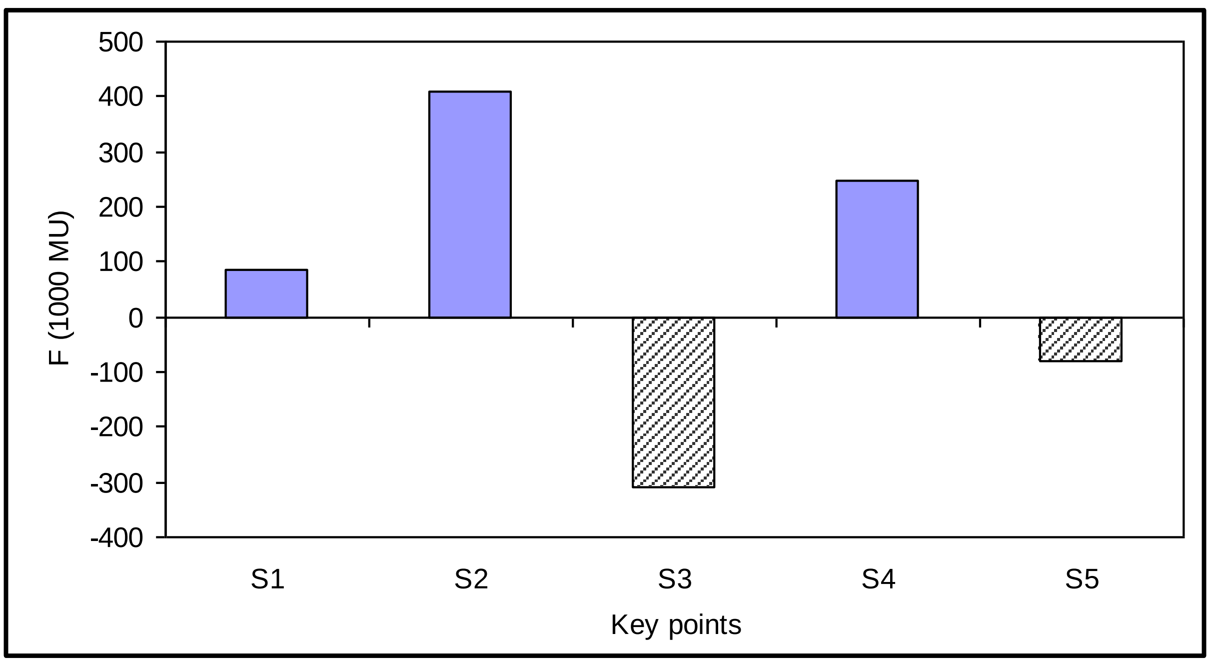


Fig. (4-7): Annual objective function concerning the flow state for (AD=125%)

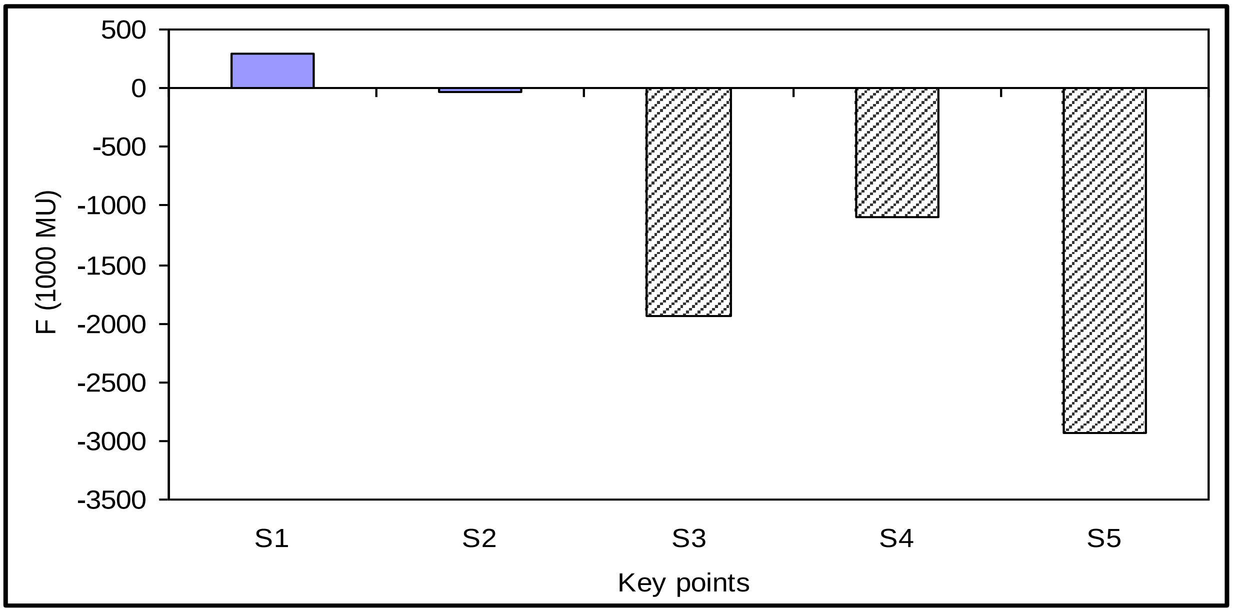


Fig. (4-8): Annual objective function concerning the flow state for (AD=160%)

Recalling that (F_k) denotes the monetary evaluation of the change of the cropped area of the k-th agricultural project through changing the agricultural density (AD). Table (4-7) through (4-10) show the values of (F_k) according to four adopted operation scenarios, namely, (AD=actual), (AD=50%), (AD=125%), and (AD=160%), respectively. However, the (AD=100%) has been considered as the base for comparison and, consequently, its (F_k) values relative to itself would be (null). The aforementioned results are summarized schematically for the considered fourteen agricultural projects in Figs.(4-9) through (4-12). Table (4-11) shows the total objective function for the operation scenarios. Figure (4-13) shows the total objective function at the stations for the flow state, Fig.(4-14) shows values of (F_k) for the agricultural projects, and Fig. (4-15) shows values of (TF) for the first part of MOD for the considered operation scenarios.

Table (4-7): Values (MU) of the partial objective function (F_k) according to the first operation scenario, (AD = actual)

k	Name of agricultural project	SAD (donum)	A (donum)	F=δ.A (MU)
1	Al-Saqlawiya	70080	80000	19840
2	Al-Ishaqi	78226	84000	11548
3	Sabaa-Al Bor	53680	38000	-31360
4	Abughraib	115246	120000	9508
5	Radhwaniya1	20495	27000	13010
6	Radhwaniya2	28435	27750	-1370
7	Al-Yusufiya	132548	111000	-43096
8	Hor Rajab	54079	49000	-10158
9	Al-Latifiya	124723	130000	10554
10	North Mussaiyab	117788	119000	2424
11	Jbalah	77774	88000	20452
12	Kusaiba	80907	93000	24186
13	South Mussaiyab	189263	193200	7874
14	Al-Shuhaimiya	114900	123000	16200
Annual total			**(MU)**	49612

Table (4-8): Values (MU) of the partial objective function (F_k) according to the second operation scenario, (AD=50%)

k	Name of agricultural project	SAD (donum)	A (donum)	F=δ.A (MU)
1	Al-Saqlawiya	70080	35040	-70080
2	Al-Ishaqi	78226	39113	-78226
3	Sabaa-Al Bor	53680	26840	-53680
4	Abughraib	115246	57623	-115246
5	Radhwaniya1	20495	10247	-20496
6	Radhwaniya2	28435	14217	-28436
7	Al-Yusufiya	132548	66274	-132548
8	Hor Rajab	54079	27039	-54080
9	Al-Latifiya	124723	62362	-124722
10	North Mussaiyab	117788	58894	-117788
11	Jbalah	77774	38887	-77774
12	Kusaiba	80907	40454	-80906
13	South Mussaiyab	189263	94631	-189264
14	Al-Shuhaimiya	114900	57450	-114900
Annual total			**(MU)**	-1258146

Table (4-9): Values (MU) of the partial objective function (F_k) according to the fourth operation scenario, (AD=125%)

k	Name of agricultural project	SAD (donum)	A (donum)	F=δ.A (MU)
1	Al-Saqlawiya	70080	87600	35040
2	Al-Ishaqi	78226	97783	39114
3	Sabaa-Al Bor	53680	67100	26840
4	Abughraib	115246	144058	57624
5	Radhwaniya1	20495	25618	10246
6	Radhwaniya2	28435	35544	14218
7	Al-Yusufiya	132548	165685	66274
8	Hor Rajab	54079	67599	27040
9	Al-Latifiya	124723	155904	62362
10	North Mussaiyab	117788	147235	58894
11	Jbalah	77774	97218	38888
12	Kusaiba	80907	101134	40454
13	South Mussaiyab	189263	236578	94630
14	Al-Shuhaimiya	114900	143625	57450
Annual total			**(MU)**	629074

Table (4-10): Values (MU) of the partial objective function (F_k) according to the fifth operation scenario,(AD=160%)

k	Name of agricultural project	SAD (donum)	A (donum)	F=δ.A (MU)
1	Al-Saqlawiya	70080	112129	84098
2	Al-Ishaqi	78226	125162	93872
3	Sabaa-Al Bor	53680	85888	64416
4	Abughraib	115246	184394	138296
5	Radhwaniya1	20495	32792	24594
6	Radhwaniya2	28435	45496	34122
7	Al-Yusufiya	132548	212077	159058
8	Hor Rajab	54079	86526	64894
9	Al-Latifiya	124723	199557	149668
10	North Mussaiyab	117788	188461	141346
11	Jbalah	77774	124439	93330
12	Kusaiba	80907	129452	97090
13	South Mussaiyab	189263	302820	227114
14	Al-Shuhaimiya	114900	183841	137882
Annual total			**(MU)**	1509780

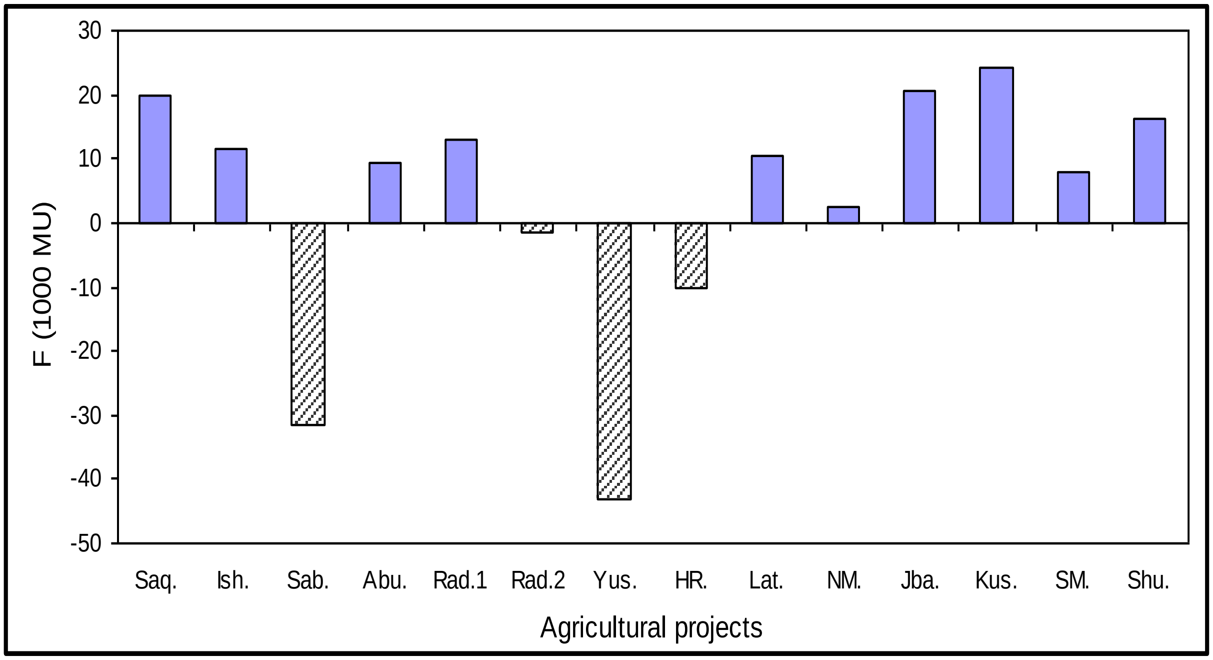


Fig. (4-9): Annual (F_k) for the served agricultural projects for (AD=actual)

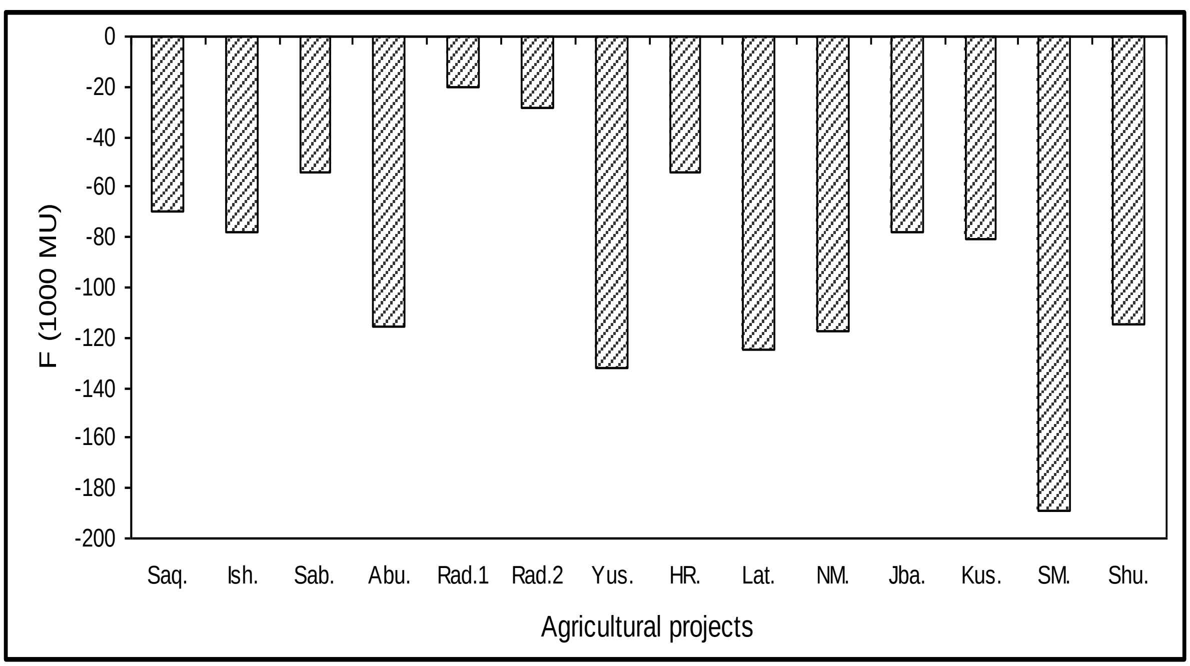


Fig. (4-10): Annual (F_k) for the served agricultural projects for (AD=50%)

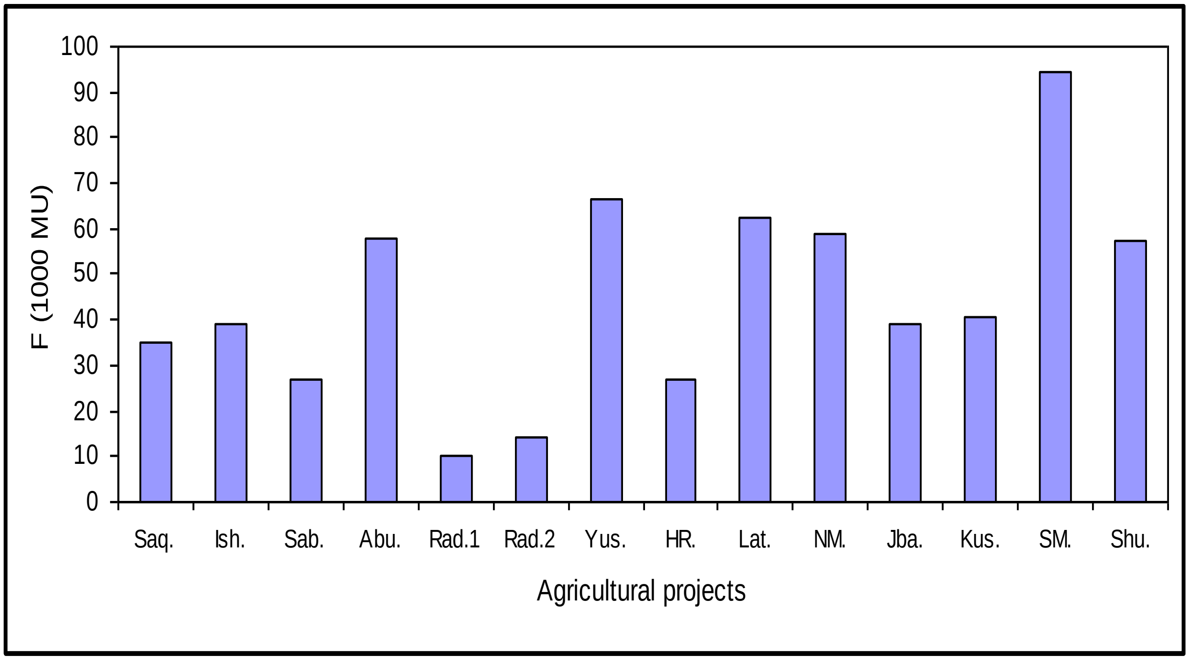


Fig. (4-11): Annual (F_k) for the served agricultural projects for (AD=125%)

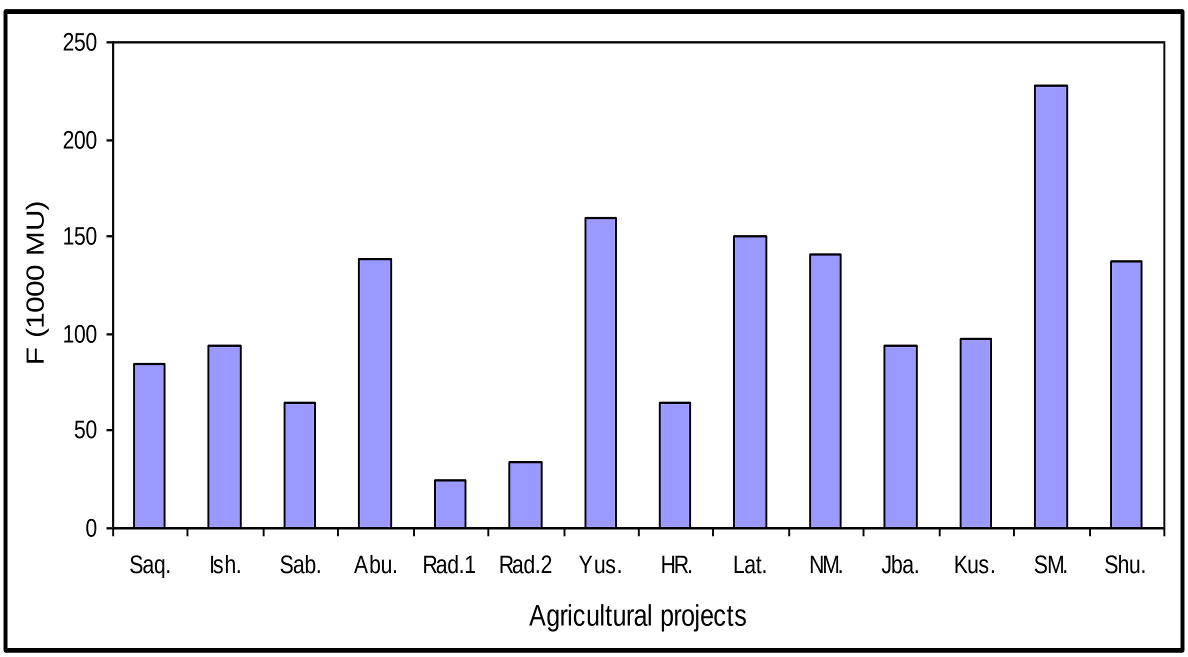


Fig. (4-12): Annual (F_k) for the served agricultural projects for (AD=160%)

Table(4-11): Total values of the objective function for the operation scenarios

Objective function	Agricultural density%				
	actual	50	100	125	160
F_{ij} (MU)	2,850,791	-2,810,214	2,352,627	351,866	-5,721,486
F_k (MU)	49,162	-1,258,146	0	629,076	1,509,780
TF (MU)	2,899,953	- 4,068,360	2,352,627	980,942	- 4,211,706

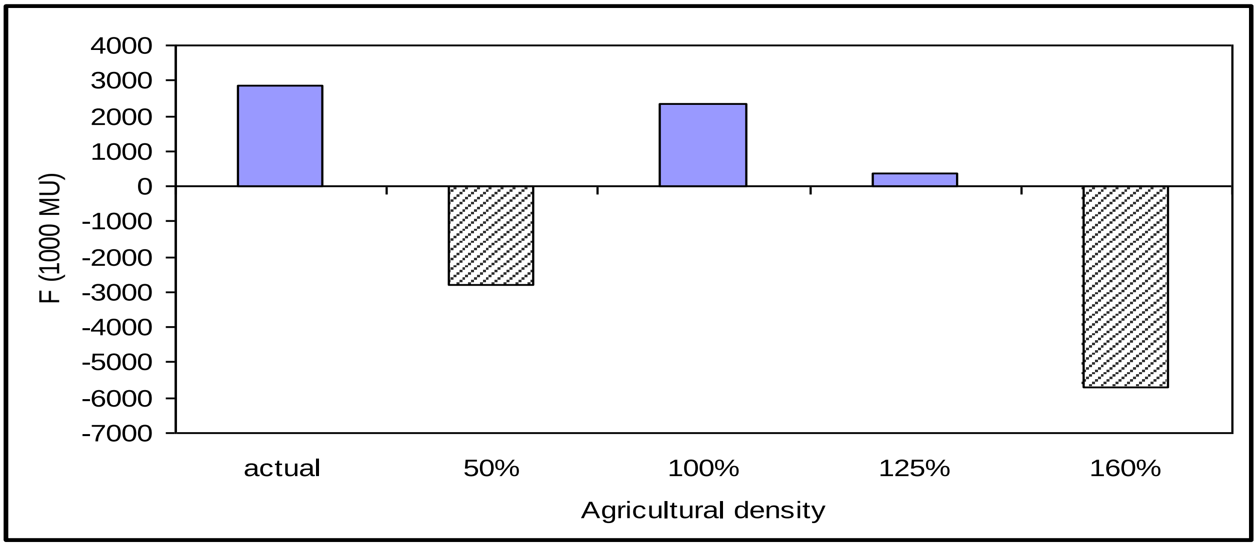


Fig. (4-13): Annual partial objective function (F_j) concerning the flow state

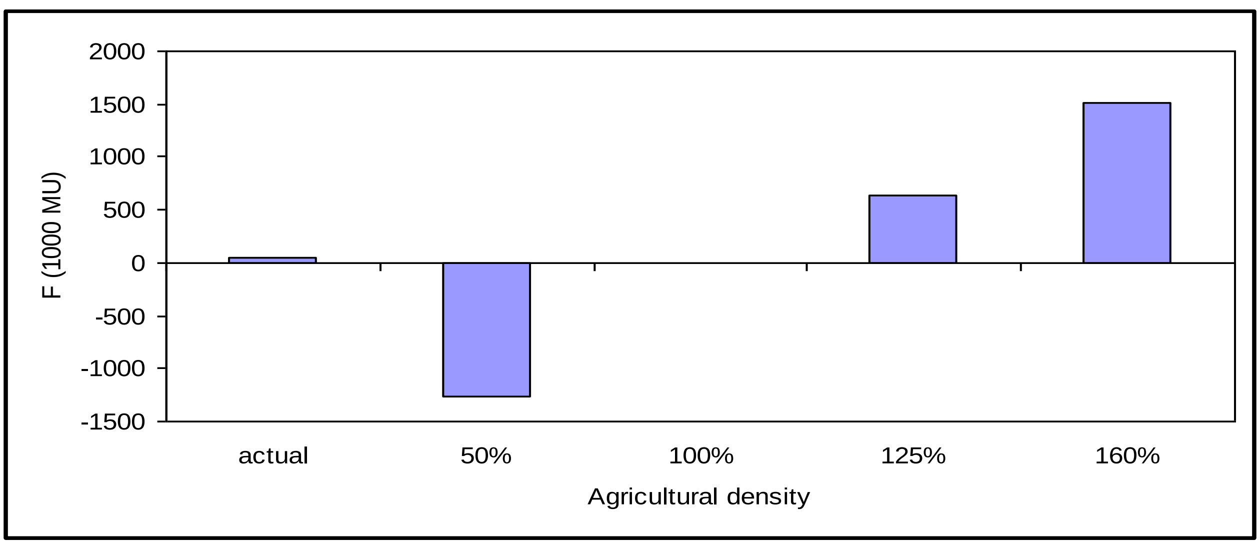


Fig. (4-14): Annual partial objective function (F_k) for the served agricultural projects

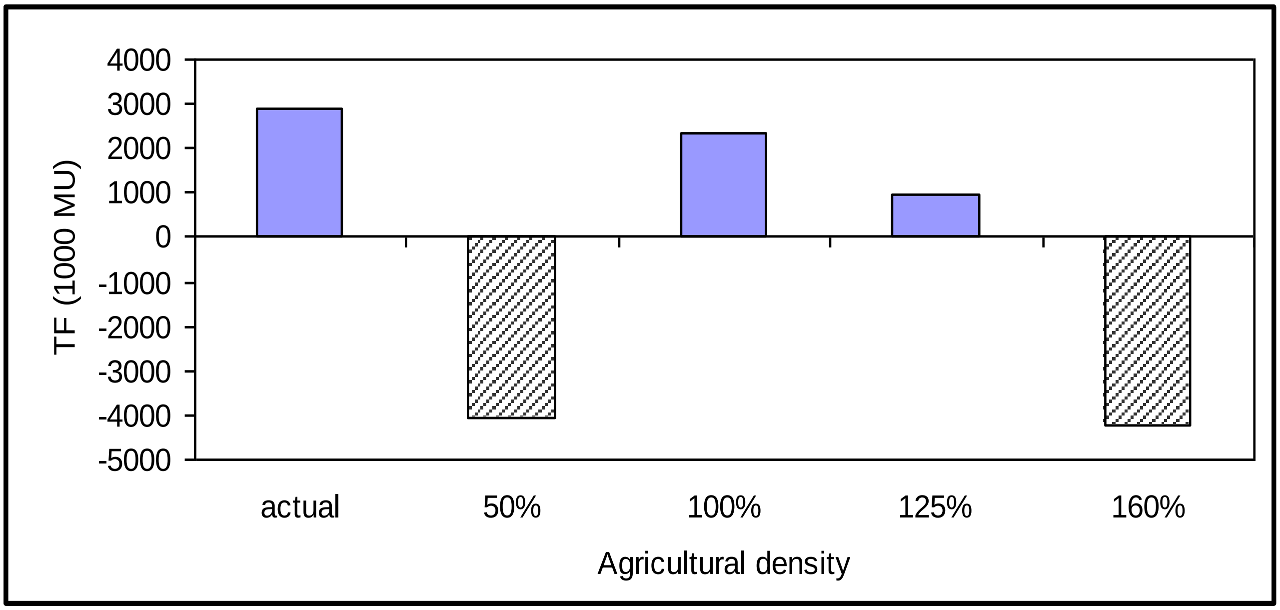


Fig. (4-15): Total annual objective function (TF)

The results showed that a value ($F_{ij} = 0$) was not found because there is no value of the flow equal to $0.5Q_{Dj}$ in any station or key point of the first part of MOD.

The number of months the flow at the considered five key points falls in each of the four flow states previously stated and for the five considered operation scenarios are given in Tables (4-12) through (4-16), respectively.

Table (4-12): Status of the flow (number of months in a water year) according to scenario (1)-[AD=actual]

Key points	$Q_{ij} < 0.5Q_{Dj}$	$0.5Q_D < Q_{ij} \leq Q_{Dj}$	$Q_{ij} > Q_{Dj}$
S1	6	6	0
S2	2	10	0
S3	0	12	0
S4	0	12	0
S5	0	12	0

Table (4-13): Status of the flow (number of months in a water year) according to scenario (2)-[AD=50%]

Key points	$Q_{ij} < 0.5Q_{Dj}$	$0.5Q_{Dj} < Q_{ij} \leq Q_{Dj}$	$Q_{ij} > Q_{Dj}$
S1	12	0	0
S2	12	0	0
S3	11	0	0
S4	12	0	0
S5	12	0	0

Table (4-14): Status of the flow (number of months in a water year) according to scenario (3)-[AD=100%]

Key points	$Q_{ij} < 0.5Q_{Dj}$	$0.5Q_{Dj} < Q_{ij} \leq Q_{Dj}$	$Q_{ij} > Q_{Dj}$
S1	9	3	0
S2	3	9	0
S3	0	11	0
S4	0	12	0
S5	0	12	0

Table (4-15): Status of the flow (number of months in a water year) according to scenario (4)-[AD=125%]

Key points	$Q_{ij} < 0.5Q_{Dj}$	$0.5Q_{Dj} < Q_{ij} \leq Q_{Dj}$	$Q_{ij} > Q_{Dj}$
S1	5	7	0
S2	0	11	1
S3	0	6	6
S4	0	7	5
S5	0	5	7

Table (4-16): Status of the flow (number of months in a water year) according to scenario (5)-[AD=160%]

Key points	$Q_{ij} < 0.5Q_{Dj}$	$0.5Q_{Dj} < Q_{ij} \leq Q_{Dj}$	$Q_{ij} > Q_{Dj}$
S1	1	10	1
S2	0	7	5
S3	0	2	10
S4	0	4	8
S5	0	1	11

4-4 : Analysis of the results

4-4-1 : the partial objective function (F_j)

With respect to the partial objective function (F_{ij}) that reflects the relative monetary evaluation of the state of the flow in the case study at the j-th key point during the i-th month of a water year, and its cumulative one (F_j). Recalling that this function is (+ve) when ($0.5Q_{Dj} < Q_{ij} \leq Q_{Dj}$); it is (null) when ($Q_{ij} = 0.5Q_{Dj}$); and it is (-ve) elsewhere.

The results for (AD = actual), summarized in Fig. (4-4), show that F(S1) is (-ve), whereas it is (+ve) for (S2), (S3), (S4), and (S5); its relative annual value is (2,850,791 MU) as given in Table (4-2). The (-ve) values at (S1) are due to ($Q_{ij} < 0.5Q_{Dj}$) during (6) months of the (12) months of a water year. It may seems logical that an improvement may be obtained by increasing the flow coming to (S1) through increasing the agricultural densities of Al-Saqlawiya, Al-Ishaqi, and Sabaa-Al Bor. However, this is not a straightforward subject [as will been in the following section, (4-5)].

The results for (AD=50%), summarized in Fig. (4-5), show that (F_j ; j=1, 2,…, 5) is (-ve) throughout because values of ($Q_{ij} < 0.5\ Q_{Dj}$) dominate.

The results for (AD=100%), summarized in Fig. (4-6), show that F(S1) is (-ve), because values of ($Q_{ij} < 0.5\ Q_{Dj}$) and (+ve) at (S2), (S3), (S4), and (S5) because of ($0.5\ Q_{Dj} < Q_{ij} \leq Q_{Dj}$).

The results for (AD=125%), summarized in Fig. (4-7), show that F(S1), F(S2), and F(S4) are (+ve), whereas it is (-ve) for (S3) and (S5) because of ($Q_{ij} > Q_{Dj}$).

The results for (AD=160%), summarized in Fig. (4-8), show that F(S1) is (+ve), whereas it is (-ve) for (S2), (S3),(S4), and (S5) because of ($Q_{ij} > Q_{Dj}$).

The full results for (F_j) are summarized in Table (4-11) and shown schematically in Fig. (4-13).

4-4-2 : The partial objective function (F_k)

With respect to the partial objective function (F_k) that reflects relative monetary evaluation of the agricultural projects. Recalling that this function is (+ve) when (AD>100%) and it is (-ve) when (AD<100%), and it is comparatively null for (AD=100%) because it has been considered as the reference for the evaluation.

The results, given in Tables (4-7) through (4-10) and shown schematically in Figs. (4-9) through (4-12) show that the relative values of (F_k) for scenario (1), (2), (4), and (5) were (49,612 MU), (- 1,258,146 MU), (629,074 MU), and (1,509,780), respectively. According to the base of evaluation of this partial objective function, the obtained results are logical.

The full results for (F_k) are summarized in Table (4-11) and shown schematically in Fig. (4-14).

4-4-3 : The overall objective function (TF)

With (TF) being the sum of (F_j) and (F_k), the results of (TF) as summarized in Table (4-11) and shown schematically in Fig. (4-15) indicate that the best results are due to scenario (1), (AD = actual) with a relative value of (2,899,953 MU). This is virtually a local optimum (as shall be seen in the following section).

4-5 : Modifying the agricultural densities of the projects to attain optimal total objective function

In view of what is mentioned in the preceding section about the possibilities of improving the overall objective function, (TF), several trials have been tested in this respect. This involved selected combinations of the agricultural densities of the respective agricultural projects, taking into consideration that (50% ≤ AD ≤ 160%). Five of the tested trials and their results, listed in a descending order according to the value of (TF), are shown in Table (4-17).

It is evident from these results that increasing (TF) from (2,899,953 MU) as for (AD=actual) to (4,666,751) as for Trial No. 1 in the table represents a very good improvement. However, this cannot be stated as the rigid global optimum, but only a nearly optimum. This is due to the fact that although too many trials have been tested, there are still too too many left.

Moreover, this research is concerned with the first part of MOD only. In a dynamic-programming problem for a system constituting several parts, when optimizing the different parts individually, the combination of the obtained optimal solutions of the parts usually not represents the global optimum solution of the system as a whole. Nevertheless, such a combination will be useful as a good initial policy to start with in the process of optimizing the whole system.

Table (4-17): Values of the objective functions for different combinations of the agricultural densities (AD%) for the involved agricultural projects

Project name		Trial No. 1	Trial No. 2	Trial No. 3	Trial No. 4	Trial No. 5
		AD%				
1	Al-Saqlawiya	160	160	125	135	100
2	Al-Ishaqi	160	150	125	140	100
3	Sabaa-Al Bor	160	140	125	115	100
4	Abughraib	150	140	125	125	90
5	Al-Radhwaniya1	125	115	100	125	105
6	Al-Radhwaniya2	125	115	100	125	85
7	Al-Yusufiya	100	90	80	90	85
8	Hor Rajab	125	115	100	110	80
9	Al-Latifiya	120	110	100	110	90
10	North Mussaiyab	120	110	100	110	85
11	Jbala	150	140	125	115	130
12	Kusaiba	140	130	125	110	105
13	South Mussaiyab	120	110	100	85	90
14	Al-Shuhaimiya	120	110	100	85	90
$\sum F_{ij}$	**(MU)**	4,138,837	3,548,770	2,593,203	2,213,101	1,576,761
$\sum F_k$	**(MU)**	527,914	521,948	184,940	64,468	-359,346
TF	**(MU)**	4,666,751	4,070,718	2,778,143	2,277,569	1,217,415

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5-1 : Conclusions

1- With respect to the routing program :

a- The suitable values of travel time (Δt) for the wave in each of the (14) subreaches constituting the case study are (8, 4, 1, 2, 4, 3, 2, 10, 1, 2, 3, 6, 4, and 9 hours), respectively.

b- The corresponding (K) values for the aforementioned subreaches were found to be (2 Δt).

c- The corresponding values of (x) were (0.15, 0.40, 0.20, 0.15, 0.40, 0.30, 0.15, 0.15, 0.15, 0.15, 0.10, 0.10, 0.10, and 0.10), respectively.

d- The verification process indicated that the developed model is dependable.

2- With respect to the optimization model:

a- Based on the assumed values of the evaluation parameters denoted as (α, β, γ) for the flow, and (δ) for the change of the agricultural area, the research indicated that the existing (actual) agricultural density is the best compared to the other four proposed agricultural densities, namely, 50%, 100%, 125%, and 160%. The former gave comparative value of (2,899,953 monetary units, MU).

b- Using combinations of proposed agricultural densities for the fourteen agricultural projects involved in this research, a plan of (160%, 160%, 160%, 150%, 125%, 125%, 100%, 125%, 120%, 120%, 150%, 140%, 120%, and 120%) for the involved projects, respectively, will yield a better comparative return of (4,666,751 MU).

c- With respect to the present design of the case study (the first part of the Main Outfall Drain):

There is no indication of underdesign or overdesign as long as the agricultural densities of the served agricultural projects will remain in the range (50%-160%).

5-2 : Recommendations

The following recommendations are proposed for future research:

1- Improving the performance of the routing model by using daily-recorded data, when available.

2- Improving the performance of the optimization model through using the officially-allocated water shares as the boundaries for the agricultural extension, together with another sets of the evaluation parameters [denoted in the text as (α), (β), (γ), and (δ)] as may sound more feasible.

3- Applying the model to a similar system, e.g., the middle part of MOD, aiming at an optimal operation of the pumping station at Nasiriya.

4- Applying the model to the combined system of the first part and second part of MOD.

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Table (A1): Discharge (m^3/sec) of the drains of the first part of MOD [After: (BWRD), 2006).

Table (A1-1): Discharge for the year 1996.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	4.900	5.800	8.500	6.700	3.400	3.810	3.420	4.000	4.310	10.900	10.870	9.400
2	**Is.**	6.500	7.400	9.600	8.8200	4.530	4.400	4.310	5.300	6.610	7.610	7.930	6.800
3	**Sb.**	2.600	3.700	4.300	3.100	2.010	2.100	1.900	2.310	3.040	3.080	3.120	2.300
4	**Ab.**	2.220	2.440	2.940	2.340	2.480	1.800	1.600	1.900	1.500	3.090	3.000	2.800
5	**Ra.1**	4.500	4.890	5.980	6.020	4.100	3.490	4.010	4.100	4.450	7.890	7.900	6.210
6	**Ra.2**	1.900	1.800	2.100	2.140	1.080	1.080	1.000	1.030	0.800	1.540	1.650	1.400
7	**Yu.**	5.400	6.300	3.400	5.410	4.910	3.520	3.400	3.010	4.340	5.120	5.200	4.540
8	**HR.**	1.200	1.500	1.300	1.000	1.000	1.200	1.200	1.000	1.020	1.000	1.010	1.200
9	**La.**	6.000	6.000	6.000	4.600	2.012	1.200	1.020	1.160	1.080	1.250	1.350	1.200
10	**NM.**	5.400	6.310	5.300	6.300	4.900	4.350	3.210	3.210	4.110	7.420	8.630	5.960
11	**Jb.**	2.100	2.090	2.500	2.000	2.310	1.400	1.040	1.540	1.960	2.400	2.300	2.140
12	**Ku.**	2.200	2.300	2.000	1.900	2.900	1.690	1.900	1.390	1.980	2.100	1.900	2.000
13	**SM.**	10.500	10.700	10.800	10.700	8.040	7.800	7.400	7.060	8.860	10.110	11.900	10.160
14	**Sh.**	1.300	1.200	1.000	1.200	1.400	1.000	1.000	1.300	1.300	1.320	1.300	1.200

Table (A1-2): Discharge for the year 1997.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	8.900	8.100	9.340	9.450	8.120	8.010	2.300	2.520	2.520	3.100	2.800	2.800
2	**Is.**	6.400	5.200	7.600	4.900	3.500	3.120	3.200	3.050	3.050	4.000	3.810	3.810
3	**Sb.**	2.530	2.000	3.420	3.500	3.000	2.950	1.550	2.000	2.000	2.750	2.700	2.700
4	**Ab.**	2.500	2.500	2.900	3.160	3.100	3.160	2.400	2.600	2.600	3.200	2.700	2.700
5	**Ra.1**	6.000	5.500	6.200	5.400	4.440	4.120	3.400	3.500	3.500	3.900	4.010	4.510
6	**Ra.2**	1.300	1.100	1.400	1.800	1.230	1.120	1.300	1.750	1.750	2.800	1.500	1.500
7	**Yu.**	4.500	4.300	4.600	4.000	3.060	3.070	3.500	3.200	3.200	4.200	3.810	3.810
8	**HR.**	1.200	1.200	1.100	1.100	1.100	1.100	1.100	1.200	1.120	1.100	1.000	1.000
9	**La.**	3.000	2.900	3.400	1.700	1.000	1.020	1.300	2.270	2.370	3.320	1.700	1.700
10	**NM.**	5.500	4.500	5.810	7.650	5.430	4.960	4.500	4.000	4.000	3.900	4.210	4.210
11	**Jb.**	2.000	1.800	2.300	2.200	2.230	2.160	1.500	1.900	1.900	3.700	2.900	2.900
12	**Ku.**	2.400	2.000	2.010	2.400	2.120	2.000	1.700	2.300	2.300	2.400	2.300	2.300
13	**SM.**	9.700	9.200	10.700	11.300	9.540	9.500	7.200	8.700	8.700	12.100	8.930	8.930
14	**Sh.**	1.100	1.200	1.100	1.100	1.100	1.100	1.200	1.200	1.200	1.200	1.100	1.000

Table (A1-3): Discharge for the year 1998.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	5.500	5.100	5.010	4.100	4.200	3.200	2.400	3.200	3.500	8.820	8.250	7.700
2	**Is.**	4.900	3.900	4.100	4.100	4.530	2.200	3.800	4.800	4.600	8.310	7.900	7.800
3	**Sb.**	3.900	2.800	3.200	2.900	3.100	1.600	1.600	5.300	4.500	4.200	3.800	3.100
4	**Ab.**	2.700	2.400	1.700	1.500	2.100	2.300	2.100	4.800	3.100	3.200	2.800	3.000
5	**Ra.1**	3.800	2.300	4.200	4.700	5.110	3.400	3.600	6.200	6.010	6.400	6.100	6.200
6	**Ra.2**	1.400	1.500	2.100	1.200	0.900	0.800	0.800	1.080	1.000	1.300	1.200	1.300
7	**Yu.**	3.500	3.200	2.800	2.500	3.400	2.400	2.300	3.102	2.100	4.400	3.800	4.000
8	**HR.**	1.100	1.100	1.100	1.100	1.120	1.100	1.100	1.210	1.110	1.110	1.010	1.000
9	**La.**	1.600	2.100	2.000	0.950	1.100	1.000	1.600	1.300	1.800	1.400	0.900	1.010
10	**NM.**	4.100	3.900	4.100	4.100	4.200	3.150	4.010	3.200	2.800	5.600	4.300	5.200
11	**Jb.**	2.400	1.900	1.500	1.250	1.300	1.900	1.600	1.400	1.700	2.300	1.700	2.400
12	**Ku.**	1.800	2.300	1.900	1.540	1.800	1.900	1.860	1.300	1.200	2.400	2.200	2.300
13	**SM.**	9.600	8.600	6.500	8.100	7.400	6.100	6.900	6.400	6.200	10.600	10.100	10.400
14	**Sh.**	1.100	1.100	1.100	1.110	1.120	1.120	1.200	1.200	1.200	1.200	1.100	1.000

Table (A1-4): Discharge for the year 1999.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	4.100	4.500	7.010	6.940	5.600	4.560	4.700	5.000	13.165	10.500	10.520	10.600
2	**Is.**	8.200	10.000	3.800	3.650	3.400	2.080	2.500	2.800	3.000	5.600	5.620	11.200
3	**Sb.**	3.800	2.080	2.960	2.800	2.500	1.820	1.900	2.000	2.500	3.050	3.060	3.500
4	**Ab.**	2.400	3.100	2.600	2.350	2.200	2.120	2.750	3.000	3.000	2.800	2.810	3.010
5	**Ra.1**	7.100	6.600	5.400	5.080	5.120	5.170	5.400	5.500	5.750	5.500	5.510	5.100
6	**Ra.2**	1.200	1.020	1.020	0.980	0.750	0.670	0.800	1.000	1.250	1.030	1.020	1.050
7	**Yu.**	4.900	4.300	3.090	2.950	2.750	2.650	3.000	3.500	3.500	3.500	3.520	4.300
8	**HR.**	1.130	1.200	1.120	1.110	1.120	1.110	1.100	1.110	1.110	1.110	1.010	1.100
9	**La.**	1.100	1.200	1.000	1.000	1.120	1.220	1.000	1.050	1.070	1.020	1.040	1.310
10	**NM.**	6.200	5.300	4.600	4.520	3.700	3.350	4.500	5.000	5.750	5.500	5.510	6.050
11	**Jb.**	2.000	2.400	2.400	2.400	1.950	1.850	1.630	1.500	1.750	1.500	1.520	2.100
12	**Ku.**	2.500	2.100	1.080	1.000	0.420	0.330	1.250	1.500	1.500	1.750	1.760	2.500
13	**SM.**	7.400	5.400	9.130	9.100	9.000	8.710	9.500	10.000	10.000	10.250	10.270	10.900
14	**Sh.**	1.200	1.110	1.110	1.110	1.110	1.120	1.100	1.110	1.100	1.200	1.100	1.000

Table (A1-5): Discharge for the year 2000.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	4.500	10.500	11.000	10.000	10.000	4.000	4.250	4.750	7.500	8.000	8.500	8.400
2	**Is.**	3.000	5.600	5.750	4.250	2.250	2.000	2.250	3.000	3.500	5.000	5.200	5.400
3	**Sb.**	2.100	3.050	3.080	2.500	2.500	1.000	1.500	1.800	3.000	3.500	3.750	3.500
4	**Ab.**	1.500	2.800	3.000	2.200	2.500	1.500	1.750	2.000	3.000	3.000	3.000	3.200
5	**Ra.1**	4.800	5.500	6.000	5.100	3.000	3.000	3.500	3.750	4.000	4.000	4.000	4.000
6	**Ra.2**	0.600	1.030	1.100	0.500	0.500	0.100	1.000	1.750	2.000	1.000	1.200	1.400
7	**Yu.**	3.000	3.500	4.000	3.000	3.500	3.000	3.500	3.500	4.000	4.000	4.000	4.000
8	**HR.**	1.110	1.100	1.100	1.100	1.110	1.100	1.100	1.110	1.110	1.110	1.010	1.000
9	**La.**	0.500	1.020	0.750	0.500	0.500	0.150	0.500	0.500	0.750	1.000	1.250	1.300
10	**NM.**	3.000	5.500	5.600	4.000	4.000	1.500	1.750	2.000	3.000	3.000	3.500	3.750
11	**Jb.**	1.500	1.050	0.750	0.500	0.500	1.015	1.250	1.000	1.050	1.000	1.250	1.450
12	**Ku.**	0.500	1.750	1.500	1.200	0.750	0.500	1.000	0.750	0.500	1.000	1.500	1.800
13	**SM.**	6.000	10.250	8.500	6.000	5.000	5.500	4.000	4.000	4.000	5.000	6.000	6.250
14	**Sh.**	1.100	1.110	1.100	1.110	1.120	1.120	1.100	1.100	1.100	1.200	1.100	1.000

Table (A1-6): Discharge for the year 2001.

Drains name		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1	**Sa.**	8.500	9.500	7.500	5.000	4.000	3.500	3.000	4.000	4.000	4.250	6.500	5.450
2	**Is.**	5.500	6.500	5.000	7.000	5.000	2.300	1.500	2.000	2.000	2.250	3.250	3.200
3	**Sb.**	3.400	4.000	4.050	3.000	2.000	1.750	1.000	2.000	2.000	2.150	3.100	3.120
4	**Ab.**	3.250	3.000	3.500	2.500	2.000	2.400	2.500	2.750	2.800	2.900	4.050	3.500
5	**Ra.1**	4.000	4.500	4.000	4.500	2.500	2.750	3.500	4.000	3.900	4.250	4.500	4.300
6	**Ra.2**	1.500	1.750	2.000	0.750	0.500	0.500	0.500	0.750	1.000	0.900	2.000	1.750
7	**Yu.**	3.750	4.000	3.500	3.000	2.000	3.100	3.500	4.000	6.000	4.000	6.000	3.500
8	**HR.**	1.110	1.100	1.110	1.110	1.100	1.100	0.250	1.110	1.110	1.110	1.010	1.100
9	**La.**	1.500	1.000	0.750	0.250	0.500	0.500	0.500	0.750	0.750	0.500	1.000	0.750
10	**NM.**	4.000	4.500	4.000	4.000	3.000	1.750	1.500	2.000	2.000	3.000	4.500	4.000
11	**Jb.**	1.500	2.000	1.750	1.000	0.500	0.300	0.250	0.250	0.250	0.300	1.500	1.250
12	**Ku.**	2.000	2.250	2.000	2.000	1.000	0.730	0.250	1.000	0.500	0.750	0.500	0.600
13	**SM.**	6.500	7.000	5.000	6.000	4.000	4.500	4.500	4.000	4.500	4.250	6.000	3.750
14	**Sh.**	1.200	1.110	1.110	1.110	1.120	1.120	1.110	1.110	1.100	1.200	1.110	1.100

Appendix A

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Appendix
B

Appendix
C

Table (B-1): Sample results of calculation of the Muskingum model at S3 of the first part of MOD in days of January for the year 2001

(hr)	Q_{O3} (m^3/hr)	Q_{C3} (m^3/hr)	PD_3 %	(hr)	Q_{O3} (m^3/hr)	Q_{C3} (m^3/hr)	PD_3 %
Date : 1/1/2001				**Date : 5/1/2001**			
0	**146561**	**146561**	**0.00**				
2	146578	146567	0.01	2	147383	147121	0.18
4	146594	146573	0.01	4	147397	147135	0.18
6	146611	146580	0.02	6	147414	147152	0.18
8	146628	146586	0.03	8	147430	147168	0.18
10	146645	146592	0.04	10	147447	147185	0.18
12	146662	146598	0.04	12	147464	147202	0.18
14	146679	146605	0.05	14	147481	147219	0.18
16	146696	146611	0.06	16	147498	147236	0.18
18	146712	146617	0.06	18	147515	147253	0.18
20	146729	146624	0.07	20	147532	147270	0.18
22	146746	146630	0.08	22	147548	147286	0.18
24	**146763**	**146636**	**0.09**	**24**	**147565**	**147303**	**0.18**
Date : 2/1/2001				**Date : 6/1/2001**			
2	146780	146642	0.09	2	147582	147320	0.18
4	146797	146649	0.10	4	147599	147337	0.18
6	146814	146655	0.11	6	147616	147354	0.18
8	146830	146661	0.12	8	147633	147371	0.18
10	146847	146668	0.12	10	147650	147388	0.18
12	146864	146674	0.13	12	147666	147404	0.18
14	146881	146680	0.14	14	147683	147421	0.18
16	146898	146686	0.14	16	147700	147438	0.18
18	146915	146693	0.15	18	147717	147455	0.18
20	146932	146699	0.16	20	147734	147472	0.18
22	146948	146705	0.17	22	147751	147489	0.18
24	**146965**	**146712**	**0.17**	**24**	**147768**	**147506**	**0.18**

Table (B-1)-continued

Date : 3/1/2001				**Date : 7/1/2001**			
2	146979	146717	0.18	2	147784	147522	0.18
4	146996	146733	0.18	4	147801	147539	0.18
6	147012	146750	0.18	6	147815	147553	0.18
8	147029	146767	0.18	8	147832	147570	0.18
10	147046	146784	0.18	10	147849	147586	0.18
12	147063	146801	0.18	12	147865	147603	0.18
14	147080	146818	0.18	14	147882	147620	0.18
16	147097	146835	0.18	16	147899	147637	0.18
18	147114	146851	0.18	18	147916	147654	0.18
20	147130	146868	0.18	20	147933	147671	0.18
22	147147	146885	0.18	22	147950	147688	0.18
24	**147164**	**146902**	**0.18**	**24**	**147967**	**147704**	**0.18**
Date : 4/1/2001				**Date : 8/1/2001**			
2	147181	146919	0.18	2	147983	147721	0.18
4	147198	146936	0.18	4	148000	147738	0.18
6	147215	146953	0.18	6	148017	147755	0.18
8	147232	146969	0.18	8	148034	147772	0.18
10	147248	146986	0.18	10	148051	147789	0.18
12	147265	147003	0.18	12	148068	147806	0.18
14	147282	147020	0.18	14	148085	147822	0.18
16	147299	147037	0.18	16	148101	147839	0.18
18	147316	147054	0.18	18	148118	147856	0.18
20	147333	147071	0.18	20	148135	147873	0.18
22	147350	147087	0.18	22	148152	147890	0.18
24	**147366**	**147104**	**0.18**	**24**	148160	147898	.018

Table (B-2): Sample results of calculation of the Muskingum model at S4 of the first part of MOD in days of January for the year 2001

(hr)	Q_{O4} (m^3/hr)	Q_{C4} (m^3/hr)	PD_4 %	(hr)	Q_{O4} (m^3/hr)	Q_{C4} (m^3/hr)	PD_4 %
Date : 1/1/2001				**Date : 5/1/2001**			
0	**214920**	**214920**	**0.00**				
3	214931	214925	0.00	3	215278	215122	0.07
6	214942	214930	0.01	6	215289	215133	0.07
9	214953	214935	0.01	9	215301	215144	0.07
12	214964	214941	0.01	12	215312	215155	0.07
15	214975	214946	0.01	15	215323	215166	0.07
18	214986	214951	0.02	18	215335	215176	0.07
21	214996	214956	0.02	21	215346	215187	0.07
24	**215007**	**214961**	**0.02**	**24**	**215357**	**215198**	**0.07**
Date : 2/1/2001				**Date : 6/1/2001**			
3	215018	214966	0.02	3	215369	215209	0.07
6	215029	214972	0.03	6	215380	215220	0.07
9	215040	214977	0.03	9	215392	215231	0.07
12	215051	214982	0.03	12	215403	215242	0.07
15	215062	214987	0.03	15	215414	215253	0.08
18	215073	214992	0.04	18	215426	215264	0.08
21	215084	214997	0.04	21	215437	215275	0.08
24	**215095**	**215002**	**0.04**	**24**	**215449**	**215285**	**0.08**
Date : 3/1/2001				**Date : 7/1/2001**			
3	215018	214966	0.02	3	215460	215296	0.08
6	215029	214972	0.03	6	215471	215307	0.08
9	215040	214977	0.03	9	215483	215318	0.08
12	215051	214982	0.03	12	215494	215329	0.08
15	215062	214987	0.03	15	215506	215340	0.08
18	215073	214992	0.04	18	215511	215345	0.08
21	215084	214997	0.04	21	215523	215357	0.08
24	**215182**	**215044**	**0.06**	**24**	**215534**	**215368**	**0.08**
Date : 4/1/2001				**Date : 8/1/2001**			
3	215193	215049	0.07	3	215545	215379	0.08
6	215204	215054	0.07	6	215557	215391	0.08
9	215209	215057	0.07	9	215568	215402	0.08
12	215221	215068	0.07	12	215580	215414	0.08
15	215232	215078	0.07	15	215591	215425	0.08
18	215244	215089	0.07	18	215602	215436	0.08
21	215255	215100	0.07	21	215614	215448	0.08
24	**215266**	**215111**	**0.07**	**24**	**215620**	**215452**	**0.08**

Table (B-3): Sample results of calculation of the Muskingum model at S5 of the first part of MOD for the period 1/1/2001-8/1/2001

(hr)	Q_{O5} (m^3/hr)	Q_{C5} (m^3/hr)	PD_5 %
Date : 1/1/2001-8/1/2001			
0	286200	286200	0.00
9	286344	286253	0.03
18	286489	286305	0.06
27	286633	286358	0.10
36	286777	286411	0.13
45	286921	286463	0.16
54	287066	286516	0.19
63	287210	286569	0.22
72	287354	286621	0.26
81	287398	286637	0.26
90	287571	286795	0.27
99	287744	286952	0.28
108	287917	287110	0.28
117	288090	287268	0.29
126	288263	287426	0.29
135	288436	287583	0.30
162	288610	287741	0.30
171	288783	287899	0.31
180	288835	287946	0.31

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS	DEFINITION	DIMENSIONS
a,b,d,m	constants.	-
Ab.	Abughraib drain.	-
AD	agricultural density.	%
A_k	planted area in the k-th agricultural project.	donum
C_o,C_1 and C_2	Muskingum routing coefficients.	-
D	flow depth.	L
F	Froude number.	-
F_k	monetary evaluation at k-th agricultural density.	MU
T	flow time.	T
HR.	Hor Rajab drain.	-
I	inflow or hydrograph ordinate at downstream section.	L^3/T
I_{SR2}	inflow of subreach 2.	L^3/T
Jb.	Jbala drain.	-
K	travel time.	T
Ku.	Kusaiba drain.	-
L	length of the reach.	L
La.	Al-Latifiya drain.	-
L_1	Length of subreach1.	L
MAD%	mean absolute deviation.	-
MOD	Main Outfall Drain.	-
MU	monetary units	-
n	number of data.	-
NM.	North Mussaiyab drain.	-
O	outflow or hydrograph ordinate at downstream section.	L^3/T
O_{S1}	outflow of station 1.	L^3/T
PD%	percent deviation.	-
Q	discharge.	L^3/T
$Q_{Ab.}$	discharge of Abughraib drain.	L^3/T
Q_C	calculated outflow.	L^3/T
Q_D	Maximum design discharge.	L^3/T
Q_{ij}	outflow at (i) month and (j) station.	L^3/T
Q_O	observed outflow.	L^3/T
R	reach.	-
Ra.1	Radhwaniya 1 drain.	-

SYMBOLS	DEFINITION	DIMENSIONS
Ra.2	Radhwaniya 2 drain.	-
S	Station on the first part of Main Outfall Drain.	-
$S_\circ$	slope of the channel bottom.	L/L
S_I	storage at upstream section.	L^3
S_O	storage at downstream section.	L^3
SAD_k	standard level of the total agricultural density	donum
SM.	South Mussaiyab drain.	
SR	subreach.	-
ΔS	storage between two consecutive routing times.	L^3
Δt	time interval for routing.	T
$V_\circ$	average velocity.	L/T
x	routing coefficient.	-
$y_\circ$	full flow depth.	L
Yu.	Al –Yusufiya drain.	-
α, β, γ	monetary evaluations.	$MU/m^3/hr$
δ	monetary evaluation.	MU/donum

LIST OF TABLES

Table (B-4) Sample results of calculation of the Muskingum model at S3 of the first part of MOD in days of January for the year 1996

(hr)	Q_{O3} (m^3/hr)	Q_{C3} (m^3/hr)	PD_3 %	(hr)	Q_{O3} (m^3/hr)	Q_{C3} (m^3/hr)	PD_3 %
Date : 1/1/1996				**Date : 5/1/1996**			
0	**117194**	**117019**	**0.15**				
2	118115	117948	0.14	2	153889	154201	-0.20
4	127267	126214	0.83	4	153928	154240	-0.20
6	127260	125310	1.53	6	153947	154260	-0.20
8	126656	124590	1.63	8	153966	154279	-0.20
10	125943	123870	1.65	10	153986	154298	-0.20
12	124503	122430	1.66	12	153782	153782	0.00
14	123783	121710	1.67	14	153792	154104	-0.20
16	123063	120990	1.68	16	154005	154318	-0.20
18	122343	120270	1.69	18	154025	154337	-0.20
20	120903	118830	1.71	20	154044	154357	-0.20
22	120183	118110	1.72	22	154064	154376	-0.20
24	**119463**	**117390**	**1.74**	**24**	**154083**	**154396**	**-0.20**
Date : 2/1/1996				**Date : 6/11996**			
2	118743	116670	1.75	2	153966	154279	-0.20
4	118023	115950	1.76	4	153986	154298	-0.20
6	117240	115230	1.71	6	154005	154318	-0.20
8	116418	116090	0.28	8	154025	154337	-0.20
10	124503	122430	1.66	10	154044	154357	-0.20
12	153850	154162	-0.20	12	154064	154376	-0.20
14	153869	154182	-0.20	14	153966	154279	-0.20
16	153889	154201	-0.20	16	153986	154298	-0.20
18	153908	154221	-0.20	18	154005	154318	-0.20
20	153928	154240	-0.20	20	154025	154337	-0.20
22	153947	154260	-0.20	22	154044	154357	-0.20
24	**153966**	**154279**	**-0.20**	**24**	**153782**	**153782**	**0.00**

Table (B-4)-continued

Date : 3/1/1996				**Date : 7/1/1996**			
2	153986	154298	-0.20	2	153792	154104	-0.20
4	153782	153782	0.00	4	153811	154124	-0.20
6	153792	154104	-0.20	6	153830	154143	-0.20
8	153811	154124	-0.20	8	153854	154165	-0.20
10	153830	154143	-0.20	10	153869	154182	-0.20
12	154005	154318	-0.20	12	153889	154201	-0.20
14	154025	154337	-0.20	14	153782	153782	0.00
16	154044	154357	-0.20	16	153792	154104	-0.20
18	154064	154376	-0.20	18	153782	153782	0.00
20	154083	154396	-0.20	20	153792	154104	-0.20
22	154005	154318	-0.20	22	153811	154124	-0.20
24	**154025**	**154337**	**-0.20**	**24**	**153830**	**154143**	**-0.20**
Date : 4/1/1996				**Date : 8/1/1996**			
2	154044	154357	-0.20	2	153782	153782	0.00
4	154064	154376	-0.20	4	153792	154104	-0.20
6	154083	154396	-0.20	6	153811	154124	-0.20
8	154005	154318	-0.20	8	153830	154143	-0.20
10	154025	154337	-0.20	10	153930	154243	-0.20
12	154044	154357	-0.20	12	154869	155182	-0.20
14	153782	153782	0.00	14	154102	154415	-0.20
16	153792	154104	-0.20	16	154122	154434	-0.20
18	153811	154124	-0.20	18	154141	154454	-0.20
20	153830	154143	-0.20	20	154161	154473	-0.20
22	153850	154162	-0.20	22	154171	154483	-0.02
24	**153869**	**154182**	**-0.20**	24	154190	154492	-0.02

Table (B-5): Sample results of calculation of the Muskingum model at S4 of the first part of MOD in days of January for the year 1996

(hr)	Q_{O4} (m^3/hr)	Q_{C4} (m^3/hr)	PD_4 %	(hr)	Q_{O4} (m^3/hr)	Q_{C4} (m^3/hr)	PD_4 %
Date : 1/1/1996				**Date : 5/1/1996**			
0	**153782**	**153782**	**0.00**				
3	153792	154104	-0.20	3	154316	154629	-0.20
6	153811	154124	-0.20	6	154335	154648	-0.20
9	153830	154143	-0.20	9	154355	154668	-0.20
12	153850	154162	-0.20	12	154102	154415	-0.20
15	153869	154182	-0.20	15	154122	154434	-0.20
18	153889	154201	-0.20	18	154141	154454	-0.20
21	153908	154221	-0.20	21	154161	154473	-0.20
24	**153782**	**153782**	**0.00**	**24**	**154180**	**154493**	**-0.20**
Date : 2/1/1996				**Date : 6/1/1996**			
3	153947	154260	-0.20	3	154200	154512	-0.20
6	153782	153782	0.00	6	154219	154532	-0.20
9	153792	154104	-0.20	9	154238	154551	-0.20
12	153811	154124	-0.20	12	154258	154570	-0.20
15	153830	154143	-0.20	15	154277	154590	-0.20
18	154102	154415	-0.20	18	154297	154609	-0.20
21	154122	154434	-0.20	21	154316	154629	-0.20
24	**154141**	**154454**	**-0.20**	**24**	**154335**	**154648**	**-0.20**
Date : 3/1/1996				**Date : 7/1/1996**			
3	154202	154515	-0.20	3	154238	154551	-0.20
6	153966	154279	-0.20	6	153766	154179	-0.20
9	153986	154298	-0.20	9	153886	154198	-0.20
12	154005	154318	-0.20	12	154105	154218	-0.20
15	154025	154337	-0.20	15	154125	154237	-0.20
18	154044	154357	-0.20	18	154144	154257	-0.20
21	154277	154590	-0.20	21	154164	154276	-0.20
24	**154297**	**154609**	**-0.20**	**24**	**154183**	**154296**	**-0.20**
Date : 4/1/1996				**Date : 8/1/1996**			
3	154161	154473	-0.20	3	154316	154629	-0.20
6	154180	154493	-0.20	6	154335	154648	-0.20
9	154200	154512	-0.20	9	154355	154668	-0.20
12	154219	154532	-0.20	12	154374	154687	-0.20
15	154238	154551	-0.20	15	154394	154706	-0.20
18	154258	154570	-0.20	18	154413	154726	-0.20
21	154277	154590	-0.20	21	154433	154745	-0.20
24	**154297**	**154609**	**-0.20**	**24**	**154497**	**154709**	**-0.20**

Table (B-6): Sample results of calculation of the Muskingum model at S5 of the first part of MOD for the period 1/1/1996-8/1/1996

(hr)	Q_{O5} (m^3/hr)	Q_{C5} (m^3/hr)	PD_5 %
Date : 1/1/1996-8/1/1996			
0	224280	224280	0.00
9	223653	223701	-0.02
18	223029	223097	-0.03
27	222424	222494	-0.03
36	221820	221890	-0.03
45	221216	221286	-0.03
54	220612	220682	-0.03
63	220008	220078	-0.03
72	219404	219474	-0.03
81	218801	218870	-0.03
90	218197	218266	-0.03
99	217593	217663	-0.03
108	216989	217059	-0.03
117	216385	216455	-0.03
126	215781	215851	-0.03
135	215177	215247	-0.03
162	214590	214614	-0.01
171	214001	213945	0.03
180	213337	213276	0.03

Table (C-3): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for January

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	34934	75861	69868	87335	111789	71820	143640
Ab.	41579	87470	83158	103948	133053	81000	162000
Ra.1	48542	104655	97084	121355	155334	81000	162000
S2	48866	105840	97732	122165	156371	81000	162000
Ra.2	58304	118139	116608	145760	186573	90000	180000
Yu.	77645	142549	155290	194113	248464	90000	180000
S3	86504	153360	173008	216260	276813	90000	180000
HR.	92937	170566	185874	232343	297398	122000	244000
La.	94025	207125	188050	235063	300880	122000	244000
NM.	102871	222233	205742	257178	329187	122000	244000
S4	103481	225720	206962	258703	331139	122000	244000
Jb.	107007	234792	214014	267518	342422	159500	319000
Ku.	113681	248380	227362	284203	363779	159500	319000
SM. and Sh.	138613	287074	277226	346533	443562	159500	319000
S5	143363	297000	286726	358408	458762	159500	319000

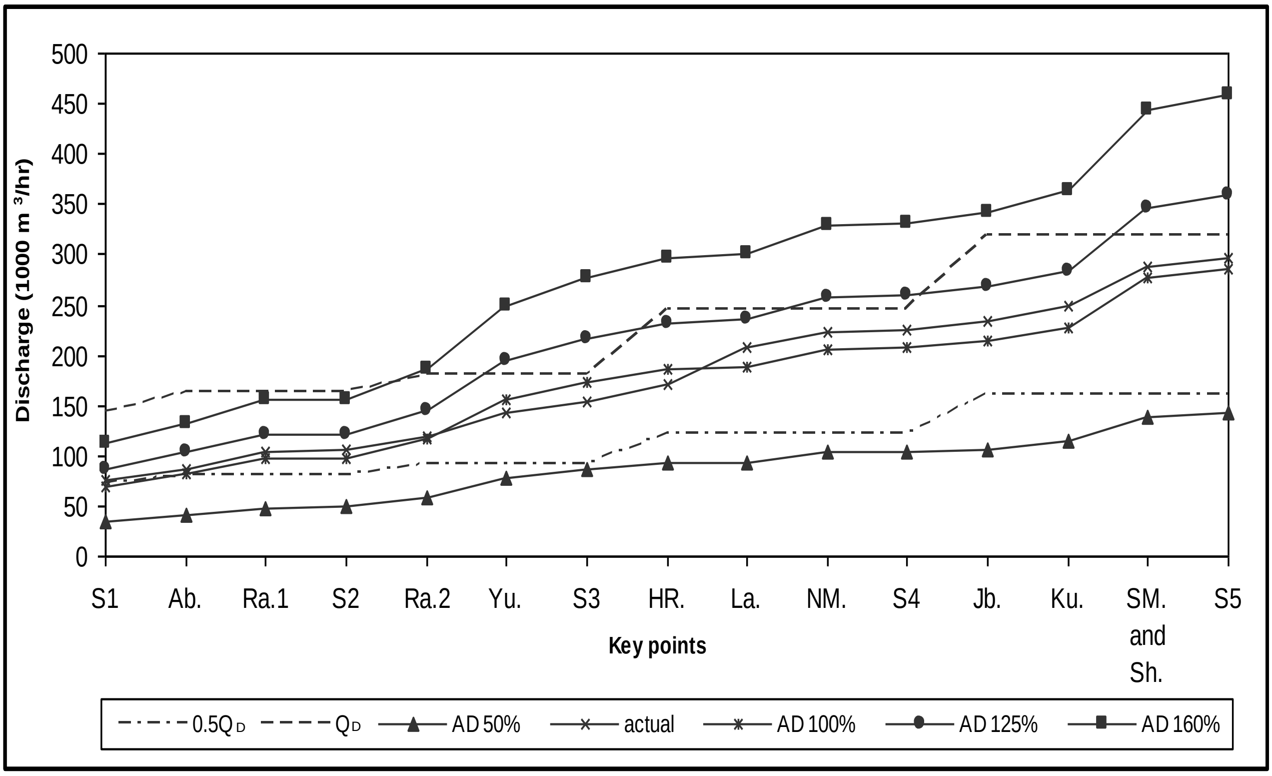

Figure (C-3): Hydrographs at the key points of the first part of MOD for the adopted scenarios for January

Table (C-4): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for February

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	40821	85407	81642	102053	130627	71820	143640
Ab.	45895	94507	91790	114738	146864	81000	162000
Ra.1	53715	115366	107430	134288	171888	81000	162000
S2	54238	117476	108476	135595	173562	81000	162000
Ra.2	63237	128360	126474	158093	202358	90000	180000
Yu.	81842	150510	163684	204605	261894	90000	180000
S3	88799	157239	177598	221998	284157	90000	180000
HR.	95097	174373	190194	237743	304310	122000	244000
La.	95190	209430	190380	237975	304608	122000	244000
NM.	100360	226164	209008	261625	333258	122000	244000
S4	104650	230268	210019	260250	336029	122000	244000
Jb.	110303	241686	220606	275758	352970	159500	319000
Ku.	118154	257870	236308	295385	378093	159500	319000
SM. and Sh.	145646	300959	291292	364115	466067	159500	319000
S5	152721	315682	305442	381803	488707	159500	319000

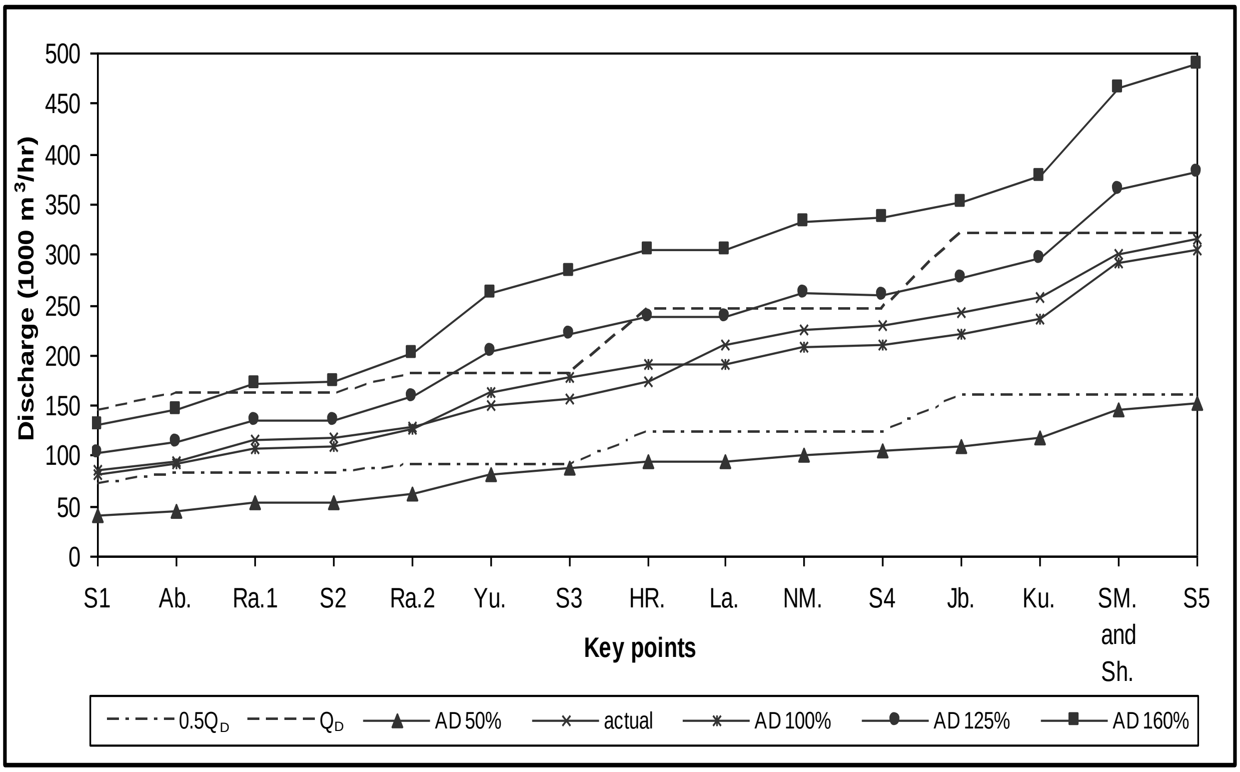

Figure (C-4): Hydrographs at the key points of the first part of MOD for the adopted scenarios for February

Table (C-5): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for March

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	46355	101575	92710	115888	140235	71820	143640
Ab.	53203	113389	106406	133008	170250	81000	162000
Ra.1	63502	136992	127004	158755	203206	81000	162000
S2	65030	140850	130060	162575	208096	81000	162000
Ra.2	70498	145175	140996	176245	225594	90000	180000
Yu.	86864	161805	173728	217160	277965	90000	180000
S3	92229	163035	184458	230573	295133	90000	180000
HR.	95587	178154	191174	238968	305878	122000	244000
La.	97757	207913	195514	244393	312822	122000	244000
NM.	100598	220635	201196	251495	321914	122000	244000
S4	103639	223057	207278	259098	331645	122000	244000
Jb.	105308	231114	210616	263270	336986	159500	319000
Ku.	110987	242543	221974	277468	355158	159500	319000
SM. and Sh.	130505	271329	261010	326263	417616	159500	319000
S5	132694	275705	265388	331735	424621	159500	319000

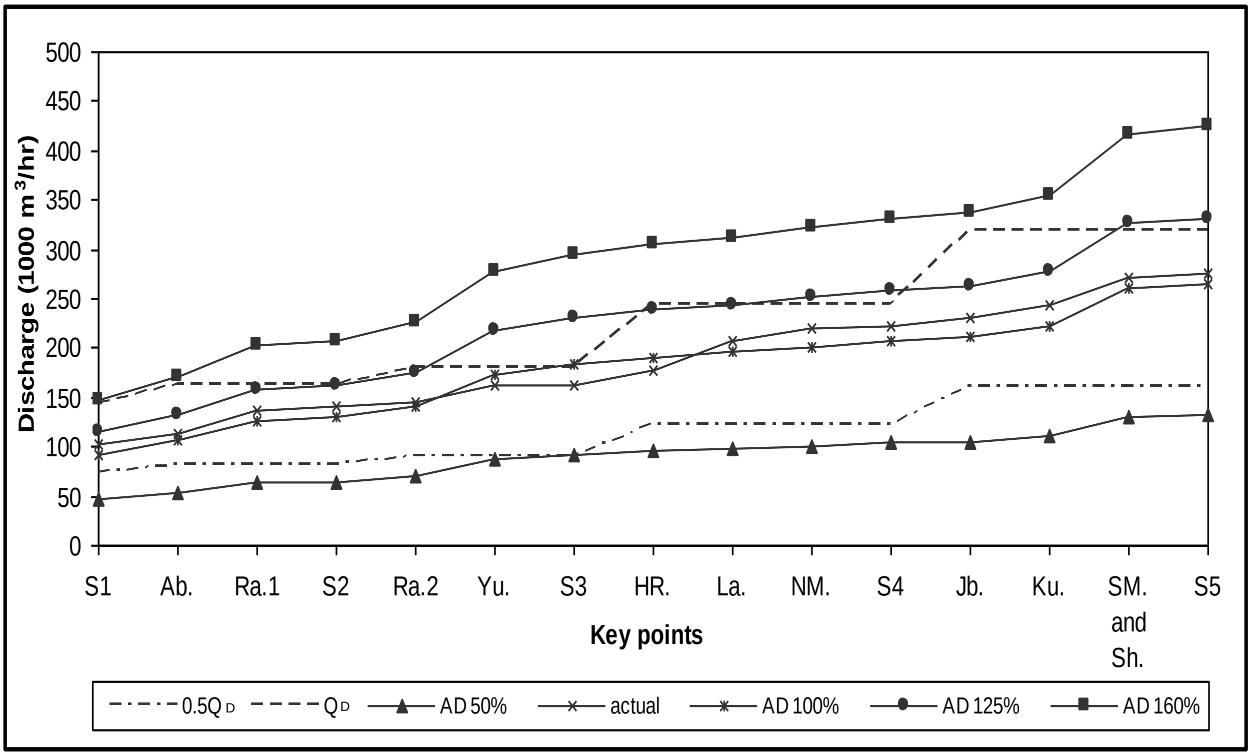

Figure (C-5): Hydrographs at the key points of the first part of MOD for the adopted scenarios for March

Table (C-6): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for April

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	44039	96271	88078	110098	140925	71820	143640
Ab.	49710	106336	99420	124275	159072	81000	162000
Ra.1	60797	131647	121594	151993	194550	81000	162000
S2	62571	135523	125142	156428	200227	81000	162000
Ra.2	68248	140527	136496	170620	218394	90000	180000
Yu.	82156	153175	164312	205390	262899	90000	180000
S3	88176	159561	176352	220440	282163	90000	180000
HR.	90587	168858	181174	226468	289878	122000	244000
La.	92867	195737	185734	232168	297174	122000	244000
NM.	93596	210702	187192	233990	299507	122000	244000
S4	97713	212330	195426	244283	312682	122000	244000
Jb.	101243	222366	202486	253108	323978	159500	319000
Ku.	109216	238202	218432	273040	349491	159500	319000
SM. and Sh.	130737	271719	261474	326843	418358	159500	319000
S5	138852	288000	277704	347130	444326	159500	319000

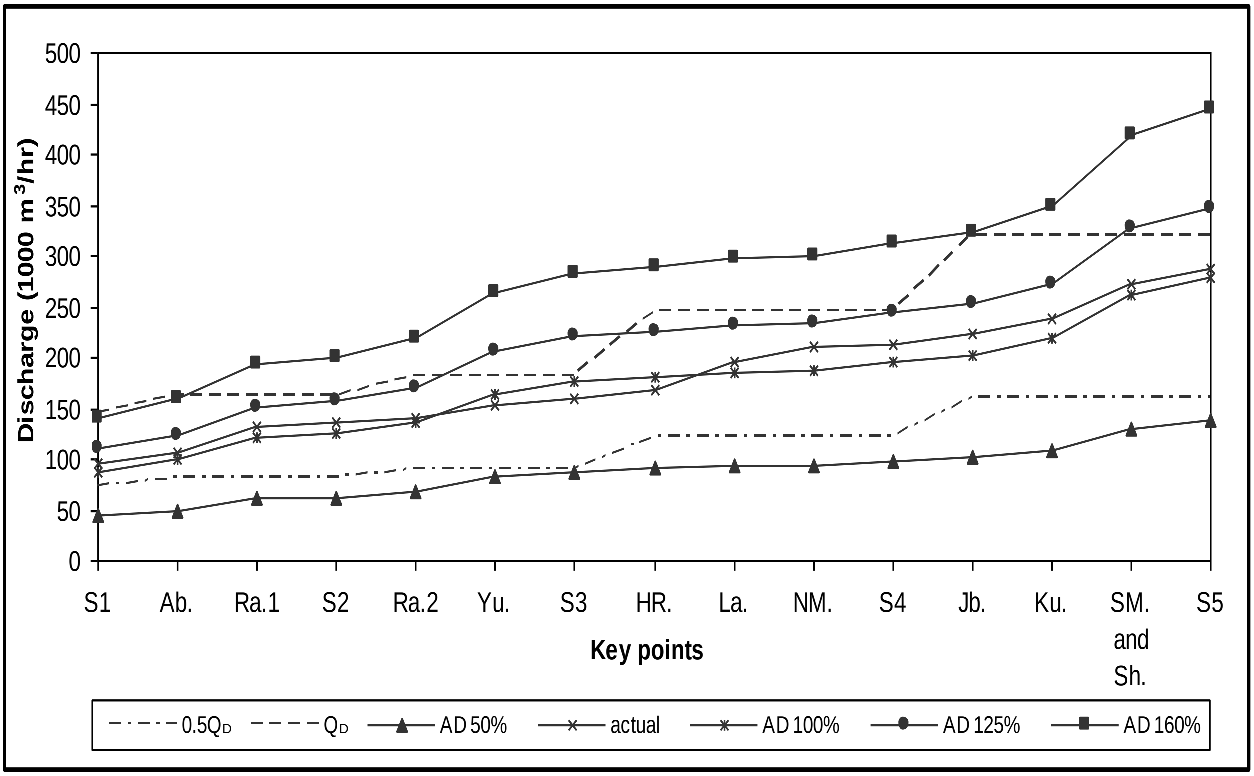

Figure (C-6): Hydrographs at the key points of the first part of MOD for the adopted scenarios for April

Table (C-7): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for May

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	33758	73073	67516	84395	108026	71820	143640
Ab.	38528	81938	77056	96320	123290	81000	162000
Ra.1	46112	99797	92224	115280	147558	81000	162000
S2	47427	102720	94854	118568	151766	81000	162000
Ra.2	52313	106380	104626	130783	167402	90000	180000
Yu.	56348	107939	112696	140870	180314	90000	180000
S3	65541	121996	131082	163853	209731	90000	180000
HR.	68442	125380	136884	171105	219014	122000	244000
La.	69946	157877	139892	174865	223827	122000	244000
NM.	70131	159921	140262	175328	224419	122000	244000
S4	77300	175362	154600	193250	247360	122000	244000
Jb.	80842	179980	161684	202105	258694	159500	319000
Ku.	88660	195876	177320	221650	283712	159500	319000
SM. and Sh.	99181	208552	198362	247953	317379	159500	319000
S5	100984	212400	201968	252460	323149	159500	319000

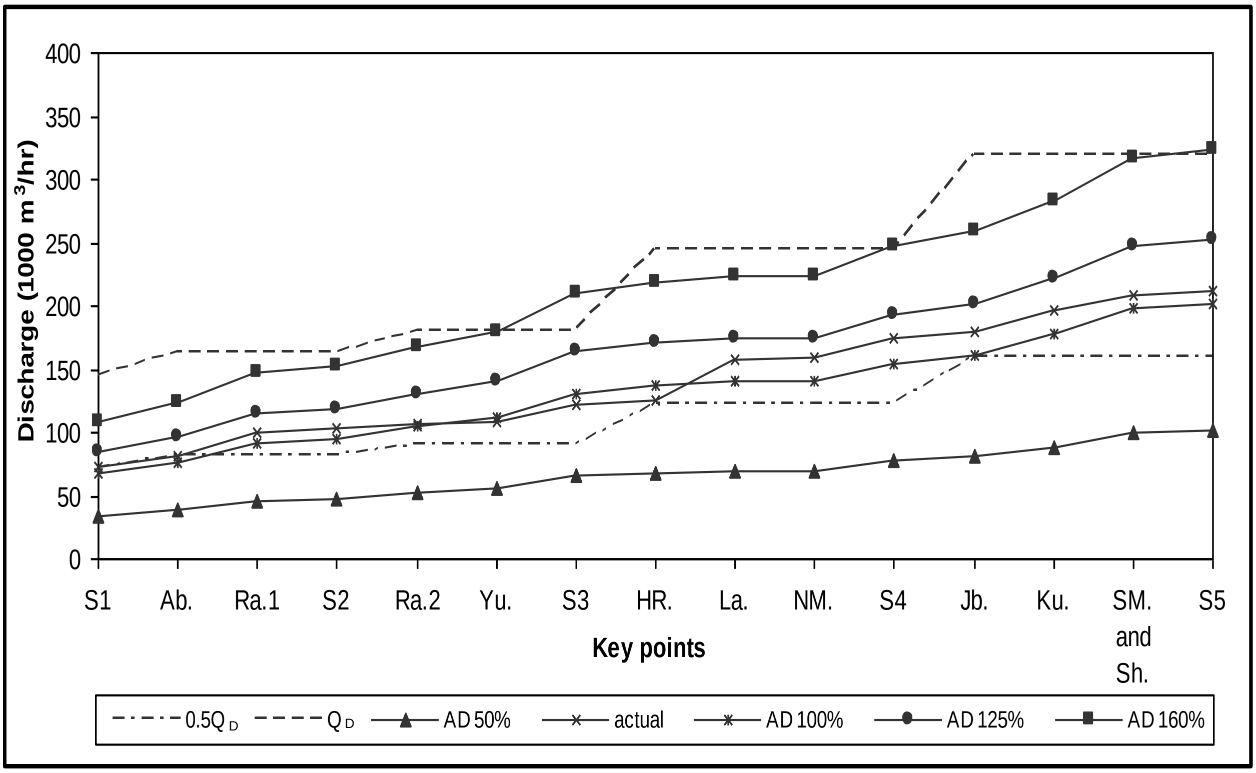

Figure (C-7): Hydrographs at the key points of the first part of MOD for the adopted scenarios for May

Table (C-8): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for June

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	24601	53895	49202	61503	78723	71820	143640
Ab.	29363	62738	58726	73408	93962	81000	162000
Ra.1	35511	76993	71022	88778	113635	81000	162000
S2	36460	78968	72920	91150	116672	81000	162000
Ra.2	40233	83499	80466	100583	128746	90000	180000
Yu.	48866	91788	97732	122165	156371	90000	180000
S3	56175	102112	112350	140438	179760	90000	180000
HR.	57093	108112	114186	142733	182698	122000	244000
La.	57429	134051	114858	143573	183773	122000	244000
NM.	64665	145525	129330	161663	206928	122000	244000
S4	65277	148523	130554	163193	208886	122000	244000
Jb.	71675	160789	143350	179188	229360	159500	319000
Ku.	79522	176833	159044	198805	254470	159500	319000
SM. and Sh.	83256	182236	166512	208140	266419	159500	319000
S5	95201	200236	190402	238003	304643	159500	319000

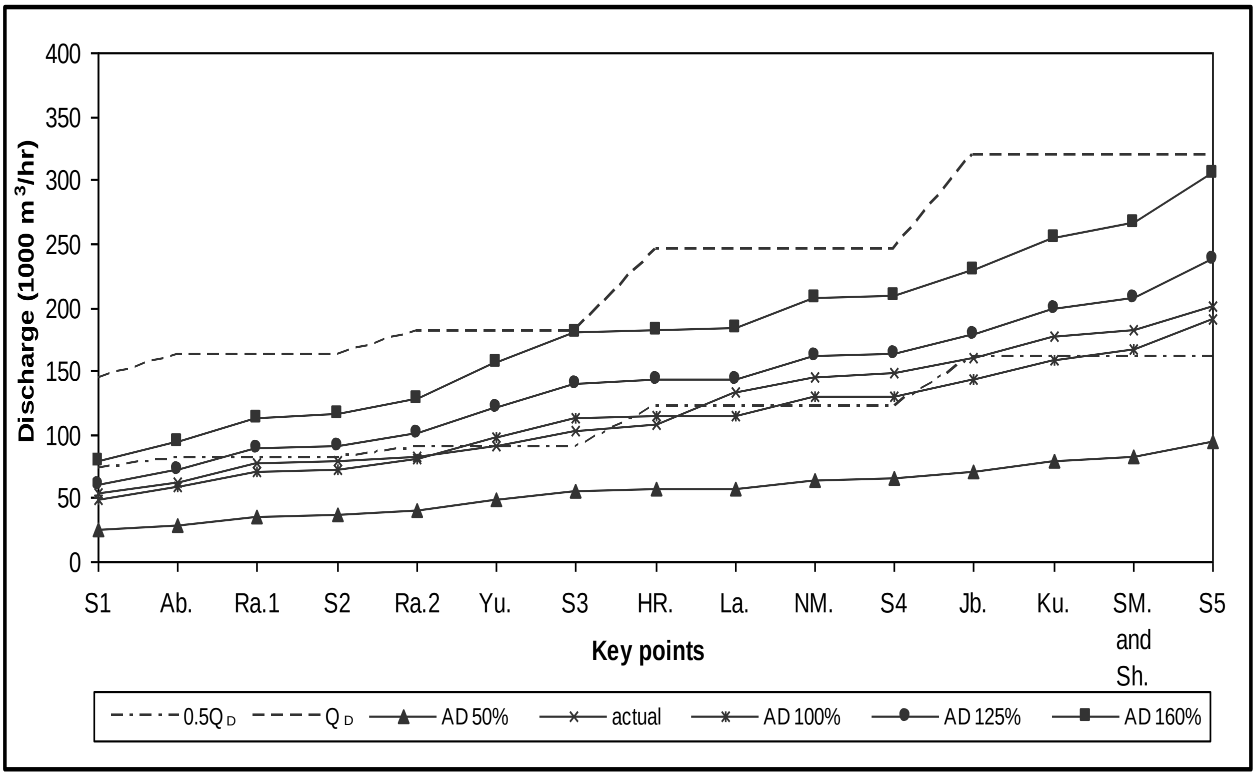

Figure (C-8): Hydrographs at the key points of the first part of MOD for the adopted scenarios for June

Table (C-9): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for July

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	22118	49205	44236	55295	75778	71820	143640
Ab.	26844	57896	53688	67110	85901	81000	162000
Ra.1	33957	73943	67914	84893	108662	81000	162000
S2	34996	75800	69992	87490	111987	81000	162000
Ra.2	37889	79081	75778	94723	121245	90000	180000
Yu.	51090	96007	102180	127725	163488	90000	180000
S3	52965	96690	105930	132413	169488	90000	180000
HR.	57615	111130	115230	144038	184368	122000	244000
La.	58037	131825	116074	145093	185718	122000	244000
NM.	64682	145095	129364	161705	206982	122000	244000
S4	67778	149458	135556	169445	216890	122000	244000
Jb.	72153	159993	144306	180383	230890	159500	319000
Ku.	80794	178424	161588	201985	258541	159500	319000
SM. and Sh.	97924	210724	195848	244810	313357	159500	319000
S5	100354	214083	200708	250885	321133	159500	319000

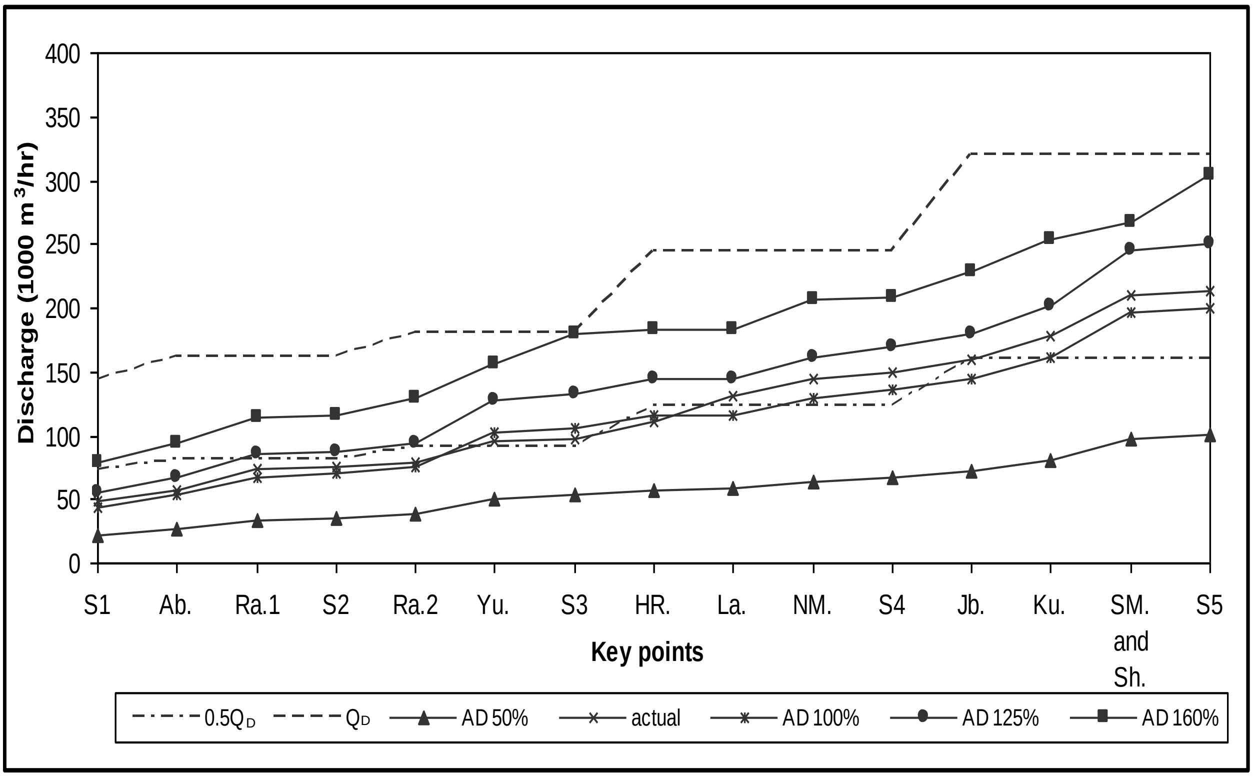

Figure (C-9): Hydrographs at the key points of the first part of MOD for the adopted scenarios for July

Table (C-10): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for August

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	23388	52040	46776	58470	74842	71820	143640
Ab.	28389	61240	56778	70973	90845	81000	162000
Ra.1	36471	79497	72942	91178	116707	81000	162000
S2	37665	81581	75330	94163	120528	81000	162000
Ra.2	40633	84748	81266	101583	130026	90000	180000
Yu.	56048	101580	112096	140120	179354	90000	180000
S3	57084	105961	114168	142710	182669	90000	180000
HR.	62998	120565	125996	157495	201594	122000	244000
La.	64002	139491	128004	160005	204806	122000	244000
NM.	67981	151656	135962	169953	217539	122000	244000
S4	68008	154374	136016	170020	217626	122000	244000
Jb.	73678	163474	147356	184195	235770	159500	319000
Ku.	83661	184150	167322	209153	267715	159500	319000
SM. and Sh.	99365	210097	198730	248413	317968	159500	319000
S5	112918	238184	225836	282295	361338	159500	319000

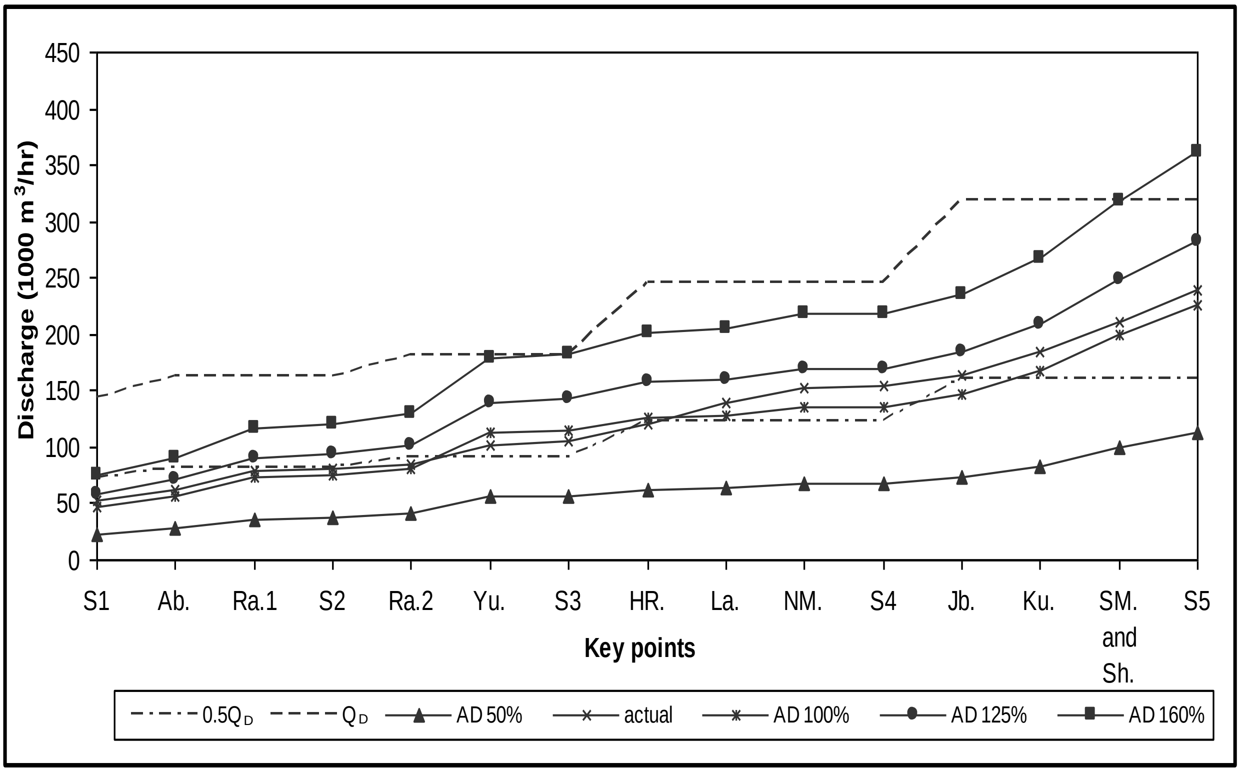

Figure (C-10): Hydrographs at the key points of the first part of MOD for the adopted scenarios for August

Table (C-11): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for September

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	25991	58538	51982	64978	83171	71820	143640
Ab.	31140	67797	62280	77850	99648	81000	162000
Ra.1	39853	86896	79706	99633	127530	81000	162000
S2	41030	88868	82060	102575	131296	81000	162000
Ra.2	44518	92641	89036	111295	142458	90000	180000
Yu.	62545	112877	125090	156363	200144	90000	180000
S3	66272	122066	132544	165680	212070	90000	180000
HR.	67768	130963	135536	169420	216858	122000	244000
La.	71210	148640	142420	178025	227872	122000	244000
NM.	72056	160085	144112	180140	230579	122000	244000
S4	74327	165484	148654	185818	237846	122000	244000
Jb.	75982	171033	151964	189955	243142	159500	319000
Ku.	87007	192868	174014	217518	278422	159500	319000
SM. and Sh.	112924	237094	225848	282310	361357	159500	319000
S5	126912	264165	253824	317280	406118	159500	319000

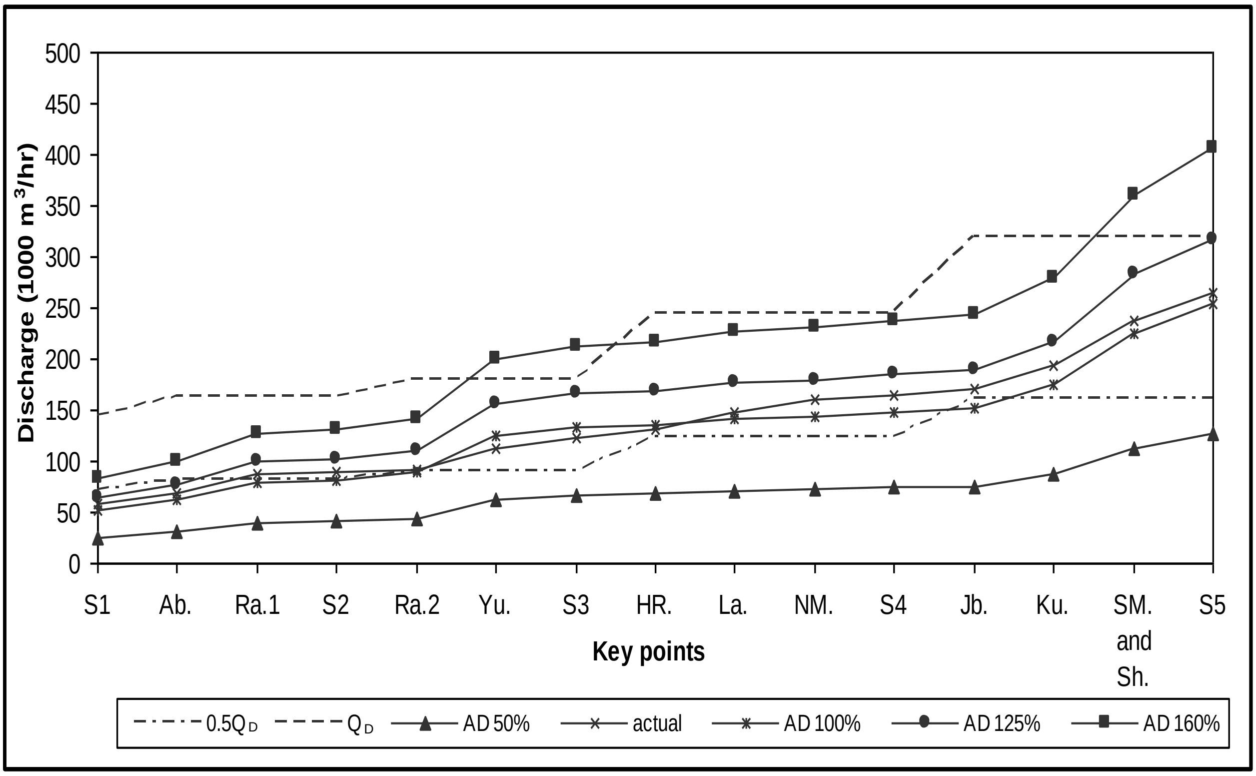

Figure (C-11): Hydrographs at the key points of the first part of MOD for the adopted scenarios for September

Table (4-1): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for October

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	28444	65434	56888	71110	91021	71820	143640
Ab.	34384	77238	68768	85960	110029	81000	162000
Ra.1	43720	95947	87440	109300	139904	81000	162000
S2	45284	98080	90568	113210	144909	81000	162000
Ra.2	49228	102317	98456	123070	157530	90000	180000
Yu.	68862	125423	137724	172155	220358	90000	180000
S3	69743	127040	139486	174358	223178	90000	180000
HR.	71330	135471	142660	178325	228256	122000	244000
La.	78293	162665	156586	195733	250538	122000	244000
NM.	79632	168765	159264	199080	254822	122000	244000
S4	81543	181495	163086	203858	260938	122000	244000
Jb.	82582	183952	165164	206455	264262	159500	319000
Ku.	90470	201493	180940	226175	289504	159500	319000
SM. and Sh.	117977	245952	235954	294943	377526	159500	319000
S5	127966	266265	255932	319915	409491	159500	319000

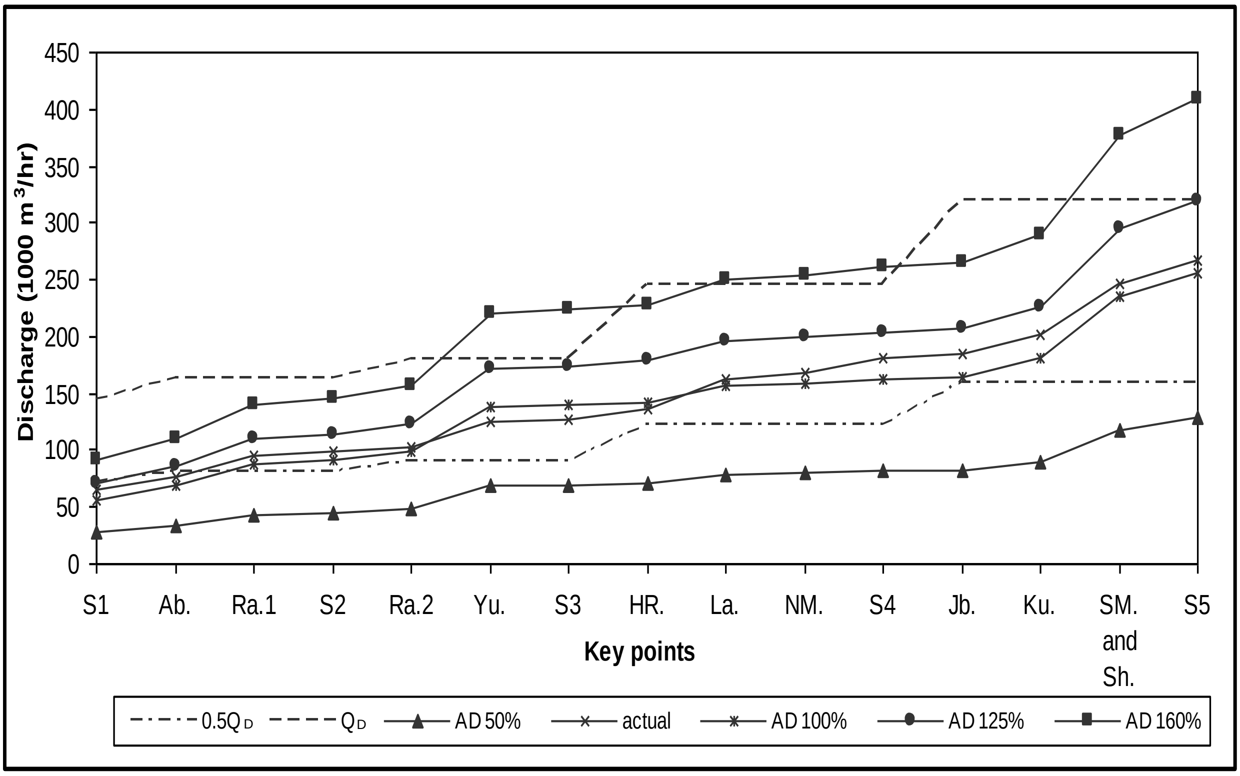

Figure (4-1): Hydrographs at the key points of the first part of MOD for the adopted scenarios for October

Table (C-1): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for November

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	30088	68261	60176	75220	96282	71820	143640
Ab.	36402	80389	72804	91005	116486	81000	162000
Ra.1	45680	97664	91360	114200	146176	81000	162000
S2	57008	120235	114016	142520	182426	81000	162000
Ra.2	63719	133358	127438	159298	203901	90000	180000
Yu.	72349	135600	145356	198373	253917	90000	180000
S3	80040	140021	152325	200100	256128	90000	180000
HR.	83064	155319	166128	207660	265805	122000	244000
La.	86568	180099	173136	216420	277018	122000	244000
NM.	88769	187122	177538	221923	284061	122000	244000
S4	89893	195907	179786	224733	287658	122000	244000
Jb.	91673	210990	198254	229183	293354	159500	319000
Ku.	106320	220853	212640	265800	340224	159500	319000
SM. and Sh.	127109	268762	254218	317773	406749	159500	319000
S5	135298	280902	270596	338245	432954	159500	319000

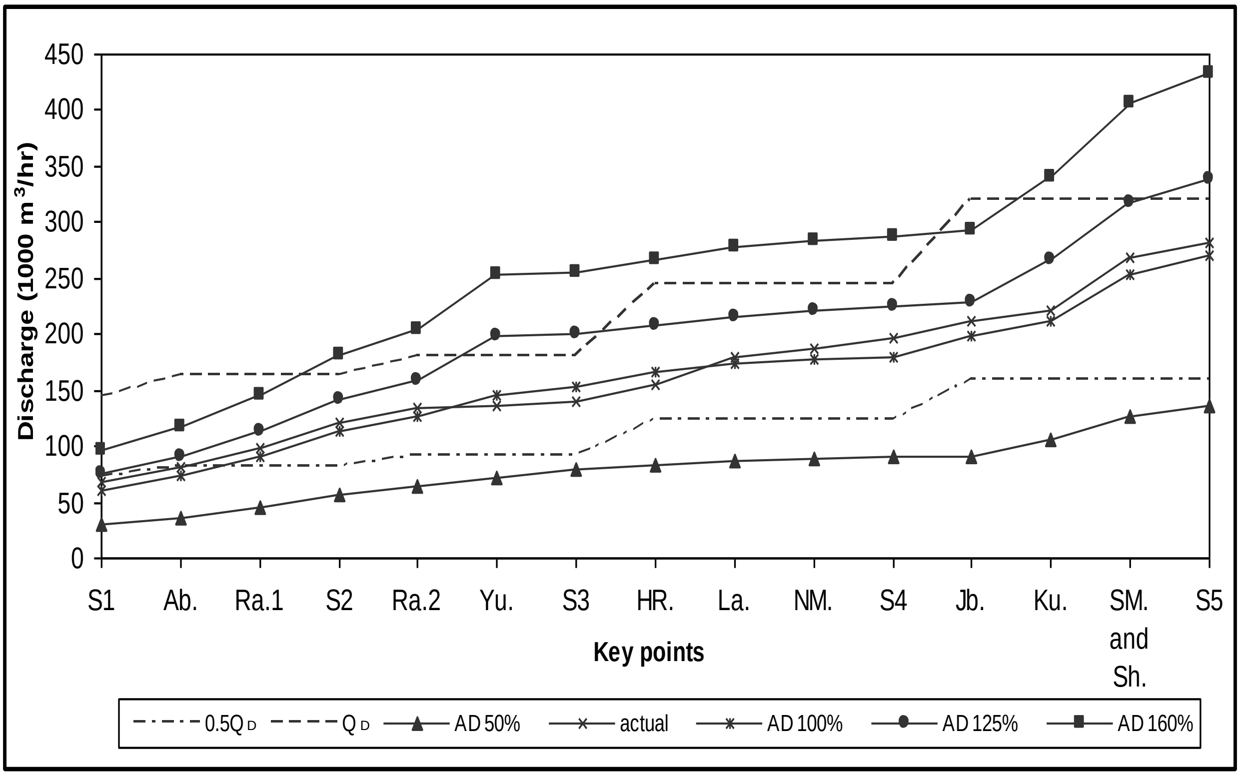

Figure (C-1): Hydrographs at the key points of the first part of MOD for the adopted scenarios for November

Table (C-2): Discharge (m^3/hr) at the key points of the first part of MOD for the adopted scenarios for December

Key points	Agricultural density%					$0.5Q_D$	Q_D
	50	actual	100	125	160		
S1	33368	80535	66736	83420	106778	71820	143640
Ab.	42698	92514	85396	106745	136634	81000	162000
Ra.1	47797	111000	95594	119493	152950	81000	162000
S2	55701	126903	111402	139253	178243	81000	162000
Ra.2	65045	135100	130090	162613	208144	90000	180000
Yu.	78430	145095	156860	196075	250976	90000	180000
S3	88230	165400	176460	220575	282336	90000	180000
HR.	90211	172574	180422	225528	288675	122000	244000
La.	98011	200871	196022	245028	313635	122000	244000
NM.	105921	220056	211842	264803	338947	122000	244000
S4	107001	225200	214002	267503	342403	122000	244000
Jb.	110708	230570	221416	276770	354266	159500	319000
Ku.	112405	240152	224810	281013	359696	159500	319000
SM. and Sh.	140354	294436	280708	350885	449133	159500	319000
S5	145295	300800	290590	363238	464944	159500	319000

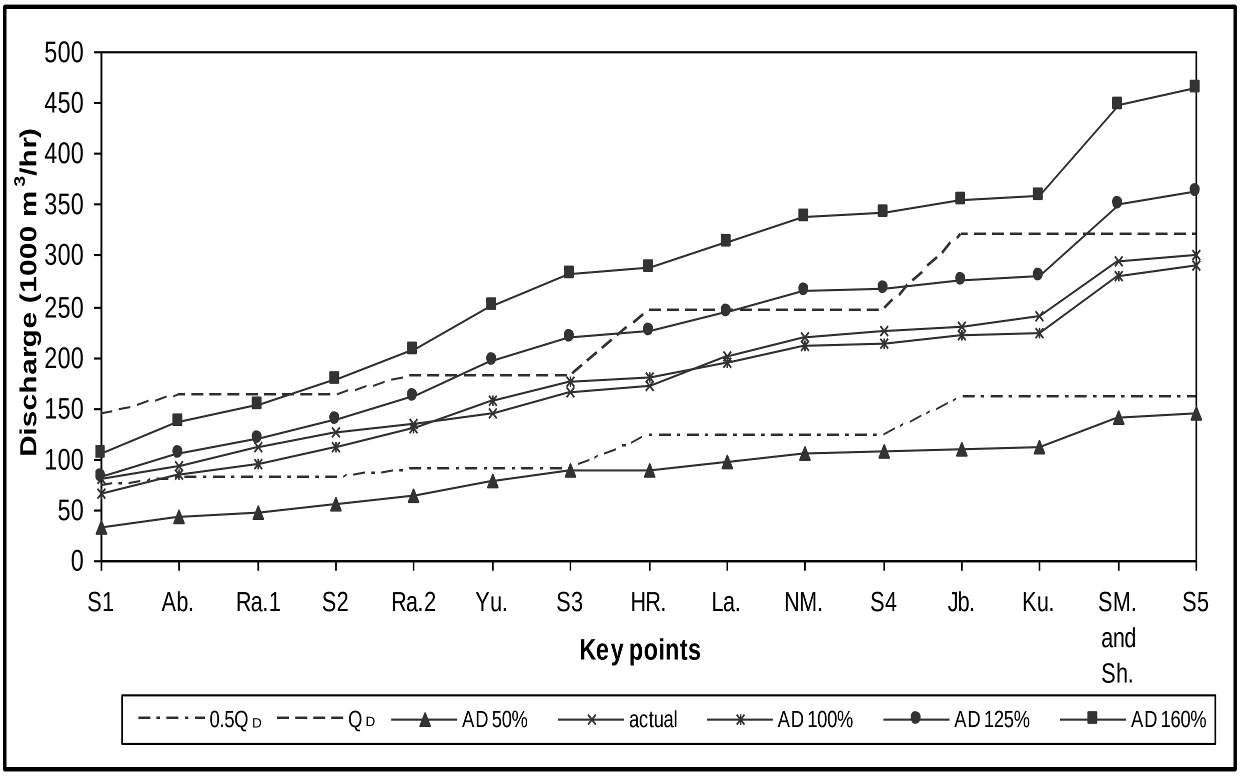

Figure (C-2): Hydrographs at the key points of the first part of MOD for the adopted scenarios for December